HUMAN SKELETAL ASYMMETRY

A study of directional and fluctuating asymmetry in assessing health, environmental conditions, and social status in English populations from the 7th to the 19th centuries.

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Rebecca Alyson STORM

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Abstract

Human Skeletal Asymmetry: A Study of Directional and Fluctuating Asymmetry in Assessing Health, Environmental Conditions, and Social Status in English Populations from the 7th to the 19th centuries.

Rebecca Alyson Storm

Keywords: directional asymmetry, fluctuating asymmetry, laterality, stress markers, developmental instability, congenital conditions.

Asymmetry is a useful tool for osteological analysis as it detects disruptions in the developmental stability of osseous structures attributed to environmental and biomechanical environments. The primary aim of this study is to establish a baseline for normal levels of asymmetry in English archaeological populations in order to distinguish between normal population variation and increased developmental instability or biomechanical stress. Directional and fluctuating asymmetry is assessed through a database of a comprehensive selection of osteological measurements throughout the skeletons of 1753 adults and subadults. The sample is from 11 archaeological sites spanning the Anglo-Saxon to the Victorian periods. The extent of developmental instability is also determined, for the first time, by employing the prevalence of population outliers. The normal range for directional asymmetry was found to be -5.79 to 6.62%, while fluctuating asymmetry was found to be 0 to 6.53%. The extent of asymmetry, however, was found to be trait specific. Deviations from normal population levels of asymmetry were found to be due to a complex mixture of biomechanical and environmental stresses influenced by age, sex, settlement type, socio-economic status, and period-specific origins of the sample populations. Possible causes of asymmetry could be discerned from comparisons of the levels of population asymmetry when placed in the context of physical activity, social networking, health, and environment developed from the historical, archaeological and osteological record.

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Storm, RA. 2008. Cranial asymmetry and developmental abnormalities. In Magilton, J., Lee, F. & Boylston, A. (Eds.) *'Lepers Outside the Gate': Excavations at the Cemetery of the Hospital of St. James and St. Mary Magdalene, Chichester 1986-93. CBA Research Report 158.* York: Council for British Archaeology, 164-173.

Storm, RA. 2007a. The stressful revolution: a rise in fluctuating asymmetry from medieval to Victorian England. In White WJ and Zakrzewski SR (eds): *Proceedings of the Seventh Annual Conference of the British Association for Biological Anthropology and Osteoarchaeology*. *BAR International Series 1712*. Oxford: Archaeopress: 95-104.

Storm, RA. 2006a. Medieval deviants: cranial fluctuating asymmetry population outliers. *Paleopathology Newsletter* (134): 14-24.

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Conference Posters

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Storm, RA. 2007b. A high prevalence of premature craniosynostosis at the medieval Hospital of St. James and St. Mary Magdalene, Chichester, England (Poster). *Program of the Seventy-Sixth Annual Meeting of the American Association of Physical Anthropologists*. Philadelphia, PA, USA. S44: 226-7.

Storm, RA. 2006b. Implications of a High Prevalence of Premature Craniosynostosis in the Medieval Hospital of St. James and St. Mary Magdalene, Chichester (Poster).The Eighth Annual Conferences of the British Association of Biological Anthropology and Osteoarchaeology, University of Birmingham, UK.

Storm, RA. 2006c. Fluctuating asymmetry in the human cranium: differential diagnoses of taphonomical, pathological, and ‘normal’ population asymmetry (Poster). *Program of the Seventy-Fifth Annual Meeting of the American Association of Physical Anthropologists.* Anchorage, AK, USA. S42: 172.

Storm, RA. 2005. The Stressful Revolution: A Rise in Fluctuating Asymmetry from Medieval to Victorian England (Poster). The Seventh Annual Conference of the British Association of Biological Anthropology and Osteoarchaeology, Museum of London, UK.

Storm, RA. and Knüsel CJ. 2004. *Fluctuating Asymmetry: Potential Applications in Human Osteology* (Poster). The Fifth Annual Conference of the British Association for Biological Anthropology and Osteoarchaeology, University of Southampton, UK.

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Chapter One

Introduction

'The most general law in nature is equity-*the principle of balance and symmetry which guides the growth of forms along the lines of the greatest structural efficiency. It is the law which gives the leaf as well as the tree, the human body and the universe itself, an harmonious and functional shape, which is at the same time objective beauty.'*

(Read 1940, p.16)

1.1 Background to Research

Throughout the course of an individual's life there is a constant struggle for the body to maintain its optimal homeostasis, a state of symmetry, while also adapting to the biomechanical demands placed upon it. Changes to an individual's skeletal structure will occur as their body adapts to increased biomechanical stresses placed upon it and it will act to buffer against any developmental insult. Directional (DA) and fluctuating asymmetry (FA) have been demonstrated to be an advantageous instrument for osteological analysis given that they detect these biomechanical adaptations and disruptions in the developmental stability of osseous structures, which can then subsequently be attributed to both exogenous and endogenous causes. These factors include biomechanical stresses, environmental stimuli, and pathological conditions, genetic predispositions, and congenital and developmental abnormalities (Livshits and Kombyliansky 1991, Møller and Pomiankowski 1993, Møller and Swaddle 1997, Palmer 1994, Palmer and Strobeck 2003, Van Valen 1962).

The topic of asymmetry has fascinated physical anthropologists for centuries. Directional asymmetry has been the focus of research concerning biomechanics, laterality and handedness (for an in depth review of directional asymmetry studies in anthropology see Chapter 2, Steele (2000b), and Auerbach and Ruff (2006)), while fluctuating asymmetry studies are concerned with the developmental stability of an organism as a measure of environmental and developmental stress (see Chapter 2). Van Valen's (1962) much quoted paper in *Evolution* could be heralded as being the defining work on the concept of asymmetry in the field of physical anthropology. However, research into asymmetries of the human skeleton has been on-going for over a century (Ruff and Jones 1981). For instance, the main premise behind fluctuating asymmetry, what became to be known as "homeostasis," can be traced as far back as Hippocrates (460-377 B.P.) (Polak 2003). Early research on asymmetry also include Whitney's (1926) study on vertebral articular processes and facets, Shultz's (1926) research on foetal growth which includes observations on the ontological origins of asymmetries, Woo's (1931) discussion on the asymmetries of the human skull, and Hoadley and Pearson's (1929) study of the internal dimensions of the skull.

Today, anthropological studies of both directional and fluctuating asymmetry are becoming more widely recognized and discussed. The majority of asymmetry studies concern directional asymmetry, especially its usefulness in detecting laterality and biomechanical adaptations. The most recent research includes Plochocki's (2004) study of directional asymmetry in the articular dimensions of the humerus, radius, femur and tibia. He concludes that there is right-sided asymmetry in both upper and lower joint surfaces, which can be attributed to the mechanical environment of an individual. Similarly, Blackburn and Knüsel (2006) found that repetitive activity related to hand dominance influenced measurements of the epicondyle of the humerus. Humeral asymmetry was also used by Sládek *et al.* (2007) to demonstrate that diaphyseal cross-sections, length, and articular breadth revealed activity-related patterns in the Late

Eneolithic and Early Bronze Age in Central Europe remained constant. However, they also found evidence of sexual division of labour in both time periods. Similar to Mays *et al.* (1999), Auerbach and Raxter (2008) examined patterns of clavicular asymmetry. They conclude that the clavicle and humerus are developmentally different due to differential loading, which is reflected in the existence and location of the asymmetry. Most recently, Pomeroy and Zakrzewski (2009) explored sexual dimorphism of cross-sectional shape and asymmetry of the long bones, concluding that, in their sample, there were no differences between the sexes. However, they suggest that their findings were inconclusive due to a small sample size.

There has recently been a profusion of studies that assess levels of fluctuating asymmetry as a measure of environmental stress. In the field of palaeoanthropology, Kegley and Hemingway (2007) demonstrate that there were greater levels of FA in the dentition of *P. robustus* and *H. habilis* than in earlier fossil hominins. In her study of crania from medieval Nubian populations, DeLeon (2007) found significant differences between the Early and Late Christian period, suggesting that the individuals were under greater amounts of nutritional and environmental stress during the Early Christian period. Gawlikowska *et al.* (2007) found that levels of fluctuating asymmetry were higher in their modern Polish sample when compared with medieval samples, and conclude that this divergence was due to differences in environmental conditions and the populations' differing socio-economic situations. Similarly, Kujanová *et al.*'s (2008) study not only demonstrated biomechanical influences for asymmetry in the upper and lower limb, but they also found increased asymmetry in their modern sample compared to their archaeological populations from Central Europe. In a study of nutritional and developmental stress in Japanese populations from the middle to late Jomon periods, Hoover and Matsumura (2008) combined both dental enamel hypoplasia and fluctuating asymmetry as markers of skeletal stress. They found a decrease in the level of FA between the middle and late periods, suggesting that an influx of immigrants during the middle period had a positive effect on developmental stability. Lastly, Storm (2008) found that the *leprosarium*/almshouse population from Chichester, UK, had elevated levels of asymmetry and an increased number of developmental abnormalities that exhibited extreme values of FA.

Although there has been a great amount of research completed on asymmetry, what constitutes ‘normal’ levels of directional and fluctuating asymmetry in human populations has yet to be methodically tested on a large sample set with measurements from the cranium, mandible, and postcranial skeleton. One may concluded from this observation that directional asymmetry studies are predominantly concerned about the direction of an asymmetry and not necessarily with the magnitude. Auerbach and Ruff (2006) were the first researchers to systematically test for the magnitude of directional asymmetry in a large sample set. However, their study only includes a limited selection of measurements on only four elements: the humerus, radius, femur, and tibia. Similarly, there has been no attempt to define normal values of fluctuating asymmetry. Most researchers have instead relied on the supposition that normal levels of asymmetry ranges from 1-5% of a measured trait (Palmer 1994). Although this figure may be an accurate estimate of normal range of asymmetry in biological studies, it has yet to be systematically tested on a large sample of human skeletal material.

1.2 Research Aims

The objective of this research was to evaluate the significance of both directional and fluctuating asymmetry in the human skeleton. The principal aim of this study was to discover a baseline for normal levels asymmetry in order to be able to help answer two primary questions about asymmetry. The first being: when does the existence of an asymmetry measured in the human skeleton become significant? Specifically, what is normal development within the population and when does a trait become a deviation from this norm? As the expression of reduced developmental instability and changes due to biomechanical stress can vary from trait to trait and do not necessarily affect the whole skeleton (Van Valen 1962; Gangestad and Thornhill 1999; Nijhout and Davidowitz 2003), this study combines a comprehensive collection of traits from both cranial and postcranial skeletal elements to evaluate normal variation in both directional and fluctuating asymmetry. Once a baseline has been defined, future researchers could easily make population comparisons and assessment of individual levels of asymmetry with the knowledge of what the expected 'normal' level of asymmetry is within an archaeological population. With this knowledge, researchers can quickly assess whether or not a population or an individual has elevated asymmetry, and in turn they will be alerted to the possibility that their population/individual may differ biomechanically or in developmental instability. Subsequently, the second question becomes, if there are deviations from the norm, be it at the individual level or at the population level, what are the causes of these deviations from developmental stability? Is it a reflection of the individual's developmental, pathological, biomechanical, environmental, demographic, social, or economic situation? To answer these questions this study assesses asymmetry differences in sexual dimorphism, differences between adults and subadults, age-related patterns, differences between urban and rural populations, as well as highlighting diachronic changes in asymmetry from the middle/late Anglo-Saxon period to the post-Medieval period in England.

This study also hypothesises that through the examination of asymmetry population outliers, it is possible to determine the presence and extent of developmental instability and pathologies, especially congenital abnormalities, within that population by the extreme nature of their individual asymmetries. Unlike other research which disregards population outliers, this research will show the usefulness of population outliers in their ability to detect an individual's inability to buffer against environmental stress. Through the analysis of outliers, an understanding of developmental stress on a population level may also be attainable. When there is an accumulation of outlying measurements within a population, one may infer that that population endured increased environmental stress and possessed less developmental stability.

1.3 Structure

The following thesis provides a review of asymmetry and presents the findings of an analysis of asymmetry in eleven English archaeological populations from the Anglo-Saxon to post-Medieval periods. Chapter Two considers how asymmetry is influenced by an organism's developmental homeostasis and the functional adaptation of bones to a variety of biomechanical stresses. It further defines and discusses the three main types of asymmetry—antisymmetry, directional, and fluctuating—and presents the findings from previous research on the general trends in the configuration of asymmetry. This is followed by a discussion of the potential influences and causes of asymmetries, including genetics, laterality and biomechanics, environmental stress, health and fitness, demographic characteristics (i.e. age and sex), and socio-economic status. Chapter

Three contextualises and presents the material used in the analysis of this research. The first half of this chapter provides a brief socio-economic and environmental historical background to the time periods from which the material for this thesis was drawn, spanning the middle Anglo-Saxon period to post-medieval England. Here, each time period has been divided into separate discussions of historical evidence of life in rural and urban environments as there are great differences is the socio-economic and environment circumstances of these two settings. The second half of Chapter Three presents the material used in the current research, including a brief discussion of each archaeological site's specific historic, archaeological and osteological background. Chapter Four, in conjunction with Appendices 1-3 in Volume Two, introduces the methods employed in this research. Chapter Five presents the results of the analysis, with supporting results in Appendices 4-10 (Volume Two) and the electronic appendices. The first half of this chapter concerns the results from initial tests of the data, including tests for outliers, measurement error, and normality and antisymmetry. The results are then separated into three main sections: analysis of directional asymmetry, fluctuating asymmetry, and population outliers. These sections are broken into five main subsections, including descriptive statistics, sex, age-at-death, archaeological site, settlement type, and period. Adults and subadults are discussed separately throughout. Chapter Six discusses these results and their wider implications for the study of asymmetry. Finally, Chapter Seven outlines the conclusions drawn from this research and suggests possible future research projects.

Chapter Two

Breaking Symmetry

2.1 Introduction

The majority of the changes to a skeleton's symmetrical development occur during ontogeny. The amount of developmental disruption during ontogeny (genetic, environmental, or biomechanical) and an individual's ability to cope with those developmental stresses are what are predominantly measured in asymmetry studies, although some asymmetrical development will occur after the developmental stages during adulthood. Section 2.2 introduces two of the main elements in the formation of asymmetry in an otherwise symmetrical human skeletal structure. These are an organism's developmental homeostasis and the functional adaptation of bones to a variety of biomechanical stresses. As both of these factors share similar ontogenetic origins, they are not mutually exclusive, and they are very difficult to separate out from one another for any particular phenotypic adaptation to genetic, environmental, or biomechanical stresses. Section 2.3 discusses the three main types of asymmetry: antisymmetry, directional, and fluctuating. Section 2.4 presents the general trends in the patterning of asymmetry found in past studies. This is followed by a discussion of the potential causes of asymmetries: genetic, laterality and biomechanics, environmental stresses, and the fitness and health status of an individual. This chapter concludes with the findings of how individual characteristics such as sex, age-at-death, and socio-economic factors may affect levels of asymmetry.

2.2 Homeostasis and Biomechanics

2.2.1 Developmental Homeostasis

Developmental homeostasis can be defined as the ability of a genotype to produce the optimal target phenotype and buffer against any environmental or genetic disturbances during ontogeny (Livshits and Kobyliansky 1991; Clarke 1993; Møller and Swaddle 1997; Nijhout and Davidowitz 2003). This process has two components: canalisation and developmental stability. Canalisation can be defined as an organism's ability to develop a specific phenotype under a *range* of genetic and environmental conditions. Developmental stability is defined as the processes that buffer an organism from disruption within *specific* genetic and environmental conditions. The main difference between the two is that canalisation controls development under a wide range of conditions, while developmental stability is the resistance to random errors under specific environmental and genetic conditions (Livshits and Kobyliansky 1991; Clarke 1993; Palmer *et al.* 1993; Møller and Swaddle 1997; Møller and Thornhill 1997; Opitz and Utkus 2001; Hallgrímsson *et al.* 2002; Nijhout and Davidowitz 2003).

Any disruption to the developmental homeostasis of an organism is referred to as developmental instability or developmental 'noise.' Developmental instability is defined as the result of the organism's inability to buffer against random environmental or genetic perturbations during development that result in deviations from the intended phenotype (Palmer *et al.* 1993; Møller and Swaddle 1997; Nijhout and Davidowitz 2003; Leamy and Klingenberg 2005). As Palmer *et al.* (1993: 202) state: "the less able an organism is to buffer itself against disturbances during development, the more likely one or more of its characters will depart from symmetry." Therefore, asymmetry is a phenotypic expression of reduced developmental stability and genetic quality (Jones *et* *al.* 2001). Levels of asymmetry are variable from trait to trait and do not necessarily have an organism-wide affect. This can be attributed to the nature of the environmental or genetic disturbance, to each trait having different sensitivities to stress, and to the processes involved in homeostasis favouring symmetry in some traits at the expense of others (Van Valen 1962; Gangestad and Thornhill 1999; Nijhout and Davidowitz 2003).

Under stressful environments a large portion of an organism's metabolism is used to cope and maintain efficient cell-to-cell communication, having little energy left for the processes involved in ensuring developmental stability (Møller and Swaddle 1997). Cells communicate through a feedback system via hormones, morphogens and neural impulses. If there is a disruption in the feedback system—either from it not responding, from it responding too quickly or too late, or if there is an under- or overcompensation to stressful condition—these self-correcting mechanisms may malfunction, creating variations in growth and thus right and left side differences. If resources are available and one side of the body is lagging behind in growth, then the feedback system should signal to the cells that catch-up growth is needed on that side. Not only do these disruptions affect the growth at one particular moment in developmental time in one particular trait, but they will influence any future growth and may have an effect on adjoining structures. These negative growth effects or perturbations will accumulate during ontogeny, thus creating higher levels of left-right asymmetries (Emlen *et al.* 1993; Palmer *et al.* 1993; Palmer 1994; Møller and Swaddle 1997; Klingenberg 2003). On the other hand, in the event of stress, organisms have also been observed to stop the growth process altogether to ensure that these developmental accidents do not happen and to resume normal growth once the stressful event has passed. Evidence of such results can be seen in skeletal and dental material in the presence of Harris lines and dental enamel hypoplasia. It should also be noted that all variations during ontogeny are not always due to developmental instability. There is also a degree of normal variation in growth that is a product of a normally functioning feedback system (Graham *et al.* 2003). One further property of the feedback system is that it will control for the development of wanted directional asymmetry (Møller and Swaddle 1997). That is, it will create directional asymmetry that is genetically predetermined, selected for, or environmentally induced.

2.2.2 Bone Biomechanics

In general, during the life of an organism bone will adapt to changes in its mechanical environment by adapting its morphology. These mechanical environments can be investigated through studying changes in bone form and any resulting asymmetries (Ruff *et al.* 2006). However, as many activities and pathologies elicit the same bony response, it is difficult to ascertain *specific* activities from bone changes (Knüsel 2002). The theory of bone functional adaptation, with its basis in Wolff's law, states that when force is applied to bone, i.e. loading, and this force is beyond the elastic properties of bone, morphological changes will occur to compensate, and this will occur in the direction of the force (Nordin and Frankel 1989; Pavlov 1994; Hallgrímsson 1998; Wilczak 1998; Knüsel 2002; Pearson and Lieberman 2004; Ruff *et al.* 2006). Pearson and Lieberman (2004: 64) summarised the three main concepts of bone functional adaptation as "bone is deposited and resorbed to achieve an optimum balance between strength and weight, trabeculae in cancellous bone tend to line up with the directions of principal stresses that they experience, and both phenomena occur through self-regulating mechanisms that respond to mechanical forces acting upon bone tissues."

The self-regulating mechanism, similar to the processes of developmental stability, is made up of a cell-to-cell communication in bone through a type of nervous system, which is a connected cellular network of osteocytes, osteoblasts and pre-osteoblasts. Osteocytes communicate with other osteocytes through protein interactions. When strain is sensed, osteogenic cells will either have no response, osteoblasts will act to grow new bone, osteoclasts will act to resorb bone, or there is Haversian remodelling (Pearson and Lieberman 2004). As with developmental instability, bone responds to mechanical stresses and strain through feedback loops. With increased strain there is bone deposition, which in turn reduces the strain returning the bone to its 'optimal customary strain level'. On the other hand, a decrease in strain will cause a loss of bone tissue to occur through resorption, which then returns it to its optimal level. This customary strain level is variable throughout the skeletal system. It is dependent on an individual's health and biological factors and it is also dependent on the type of strain and previous loading history (Ruff *et al.* 2006). The elastic property of bone will allow it to return to is normal shape and size, but if it reaches its yield point the bone will permanently deform, and if the force continues, fractures will occur (Pearson and Lieberman 2004). The normal state of bone is a homeostasis between osteoblastic and osteoclastic activity, but if normal loading to the bone is increased, the osteoblasts will favour modelling over remodelling to help compensate. This new stimulation will in turn cause the bone to hypertrophy, in that it will increase in both content and in dimension. If there is a reduction in loading, bone will atrophy. These processes can happen quickly or over a long period of time (Trinkaus *et al.* 1994; Hallgrímsson 1998; Wilczak and Kennedy 1998; Roberts and Manchester 1999; Knüsel 2000a; Knüsel 2000b; Steele 2000a; Lazenby 2002).

Adaptations in bone morphology are at their greatest during the growth period. This growth period extends into young adulthood, and even past the period of epiphyseal fusion as the body is still increasing bone mass although not bone length (Auerbach and Ruff 2006; Ruff *et al.* 2006). This has been demonstrated in a study by Ruff *et al.* (1994) who found that the length of the femur increases in early adolescence and levels off during late adolescence, while the diaphysis continues to increase to its 'normal' size into the third and fourth decade. Further, Hallgrímsson's (1998; 1999) morphogenetic drift model states that asymmetry will increase and accumulate with developmental time as bone is continually remodelled throughout ontogeny and in later adult life. The slower a skeletal structure grows, the more asymmetry will accumulate. It has also been found that juvenile bone has a greater response to biomechanical stresses, and hence a greater impact on bone morphology than in adults. This is due to the lessened sensitivity of adult cells to environmental stimuli and having decreased modelling and remodelling responses (Knüsel 2000b; Pearson and Lieberman 2004; Ruff *et al.* 2006).

2.3 Definitions of Asymmetry

Due to the nature of the developmental process outlined above, an organism can never be perfectly symmetrical (Palmer *et al.* 1993; Palmer 1996). Asymmetry is difficult to define accurately because of the complex nature of the causes of asymmetry, which still remain elusive. Although not the first, Van Valen's (1962) work on asymmetry has been quoted as being the defining source of asymmetry. He defines three main types of asymmetry found in bilateral structures such as the human skeleton. These are directional asymmetries, antisymmetries, and fluctuating asymmetries (Figure 2.1). It should be noted that all three asymmetries are interrelated and not necessarily separate phenomena occurring at one time in the same trait. This is especially the case with directional and fluctuating asymmetry (Van Valen 1962; Kark 2001). This trait-specific asymmetry has been demonstrated in numerous studies (Livshits *et al.* 1988; Livshits and Kobyliansky 1991; Clarke 1993; Pomiankowski 1997; Gangestad and Thornhill 1999; Badyaev *et al.* 2000; Lazenby 2002; Leamy and Klingenberg 2005; Auerbach and Ruff 2006; DeLeon 2007; Sengupta and Karmakar 2007), including the present.

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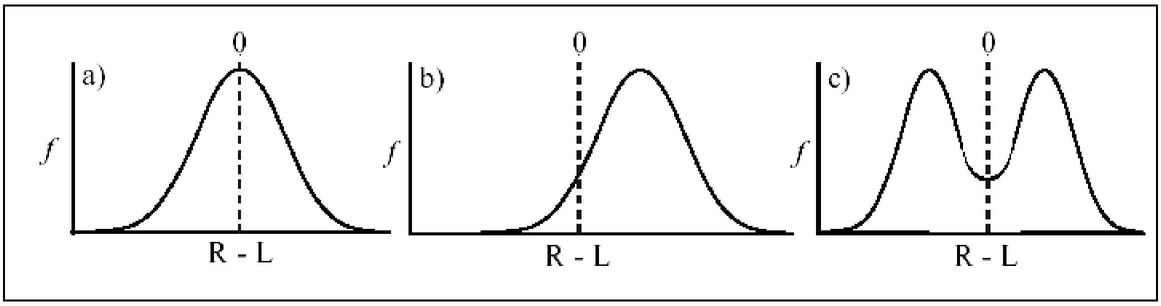

Figure 2.1: The three main types of R-L asymmetries: a) fluctuating asymmetry b) directional asymmetry and c) antisymmetry (modified from Palmer 1994).

2.3.1 Antisymmetry

Antisymmetry (AA) occurs when asymmetry is normally present but varies at random in which side it predominantly occurs (Van Valen 1962; Palmer and Strobeck 1986; Steele and Mays 1995; Møller and Swaddle 1997; Palmer 2005) and has a platykurtic or bimodal distribution about a mean of zero (Palmer and Strobeck 1986; Livshits and Kobyliansky 1991; Palmer and Strobeck 2003). In other words, there is no preference in development between the right and left side; it is all down to chance occurrences. An example of antisymmetry can be seen in studies of the asymmetrical claw size of male fiddler crabs. The male is born with equal-sized claws, but if one is damaged, the claw will drop off and it will grow a new smaller, female-sized claw. The probability of damage to either the right or left claw is equal and small claws are found with equal occurrences, therefore it is by chance that one side is larger than the other (Neville 1976).

2.3.2 Directional Asymmetry

Directional asymmetry (DA), also known as fixed or differentiated-directional asymmetry, occurs when the development of one side of an organism is systematically favoured over the other. This directional bias is seen as a normal distribution about a mean other than zero (see Figure 2.1) (Van Valen 1962; Palmer and Strobeck 1986; Livshits and Kobyliansky 1991; Palmer 1994; Steele and Mays 1995; Møller and Swaddle 1997). Similar to fluctuating asymmetry, DA will accumulate over time in both ontogeny and into adulthood (Hallgrímsson 1998). An example of this directional drift can be seen in the in the sinistral (left) or dextral (right) spiral of the snail's shell (Neville 1976), in *situs solitus*, the naturally asymmetrical layout of the organs in humans (Aylsworth 2001; McManus 2002), and in human handedness.

As will be seen with fluctuating asymmetry, directional asymmetry has multiple causes. Two of the main causes of directional asymmetry are the genetic make-up and the biomechanical environment of a developing organism. Although many studies have found that DA has a significant genetic component (Palmer 1994; Møller and Swaddle 1997), other studies have found minimal genetic influences on DA, comparable to that of fluctuating asymmetry (Graham *et al.* 1998). These differences in findings can be due to the species and trait under examination. In humans, although it is argued there is a genetic basis to handedness (see section 2.4.2), the majority of DA most likely occurs as a response to an individual's biomechanical predilections.

Although usually dismissed as not being able to contribute to our understanding of developmental instability, there are some studies that have found that DA can provide insights about environmental stress. This is due the fact that, along with the directional component caused by genetic or biomechanical activity, developmental noise (and thus fluctuating asymmetry) may also exist within a trait that increases, or decreases, the direction of the asymmetry (Van Valen 1962; Palmer 1996; Møller and Swaddle 1997; Lazenby 2002; Palmer and Strobeck 2003). As Møller and Swaddle (1997: 79) suggest, "directional selection gives rise to an increased sensitivity of the development processes to the effects of adverse environmental conditions and the disruption of co-adapted genomic complexes that both generate developmental instability." In addition, some studies have demonstrated that FA can change to DA in a stressful environment (Møller and Swaddle 1997; Kark 2001; Leamy and Klingenberg 2005). As Kark (2001: 2004) point out: "searching for these shifts, rather than excluding traits that show non-classical FA distributions, may potentially lead to important insights, and to a better understanding of underlying factors of ecological and environmental patterns in bilateral asymmetry."

Directional asymmetry is by far the most studied of the three types of asymmetry. These studies encompass a wide range of disciplines from biology to clinical medicine, from dentistry to physical anthropology. For studies concerning human asymmetries, the main focus has been concerned with the connection between DA and biomechanics and human laterality or with the impact of traumatic and pathological processes. However, there are a few studies which utilise DA as an indicator for developmental instabilities. Bioarchaeological studies of human skeletal material include those concerning the cranium (Woo 1931; Holloway and De La Costelareymondie 1982; Pirttiniemi and

Kantomaa 1992; Berge and Bergman 2001; Sommer *et al.* 2006), the clavicle (Mays *et al.* 1999), the humerus (Stirland 1993a, 1993b; Trinkaus *et al.* 1994; Selvaraj *et al.* 1998; Wilczak 1998; Tanaka 1999; Knüsel 2000a; Rhodes and Knüsel 2005; Blackburn and Knüsel 2006; Sladek *et al.* 2007), the hand (Lazenby 1994; Mays 2002), the sacrum (Plochocki 2002), multiple bones (Schultz 1937; Schulter-Ellis 1980; Ruff and Jones 1981; Ruff and Hayes 1983; Stirland 1993a; Ruff *et al.* 1994; Huggare and Houghton 1995; Steele and Mays 1995; Sansibano-Collilieux and Morello 1996; Čuk *et al.* 2001; Plochocki 2004; Auerbach and Ruff 2006; Auerbach and Raxter 2008; Pomeroy and Zakrzewski 2009), and non-metric traits (Trinkaus 1978). The significance of these studies will be discussed in the following sections.

2.3.3 Fluctuating Asymmetry

Fluctuating asymmetry (FA) has been found to be a useful measure of developmental instability as it is related to canalization of development and is the direct result of disturbances in developmental stability. Fluctuating asymmetry occurs as variation in the right and left sides of bilateral structures when their natural development has been disrupted. These variations within an individual or population are random, independent, and are usually of small differences of less that 5% of the measurable trait (Van Valen 1962; Møller and Pomiankowski 1993; Palmer 1994; Møller and Swaddle 1997; Gangestad and Thornhill 1999; Klingenberg 2004). FA is defined as having a normal distribution about a mean of zero (see figure 2.1) (Van Valen 1962; Palmer and Strobeck 1986; Livshits and Kobyliansky 1991; Palmer 1994; Palmer and Strobeck 2003), although this is not always the case. Many studies have demonstrated that FA is often non-normally distributed, with the most common distribution being leptokurtosis (Gangestad and Thornhill 1999; Babbitt 2006). This non-normal distribution is mainly due to individual differences in developmental stability and differing levels of FA within subpopulations of a larger sample (Babbitt 2006). For humans these subpopulations include sex-linked and age-related differences, genetically isolated or diverse populations, geographically different populations, and populations from stressful and non-stressful environments. If there is a mixture of fluctuating asymmetry and low levels of DA, then FA can be defined as deviations away from that directional mean asymmetry, and thus can be corrected for if necessary (Klingenberg 2003; Palmer and Strobeck 2003). However, many researchers have stated that this separation cannot be satisfactorily achieved (Palmer and Strobeck 1986; Palmer *et al.* 1993; Palmer 1994; Graham *et al.* 1998; Palmer and Strobeck 2003; Stige *et al.* 2006). Not only are asymmetries a complex mixture of types, as noted above, absolute symmetry may be impossible to achieve in continuous traits, as the attainment of stability may require a small amount of variability to compensate for natural fluctuations in the feedback system (Graham *et al.* 1993; Graham *et al.* 2008).

Unfortunately, the exact cause of fluctuating asymmetry in an organism is still not well understood. Similar to directional asymmetry, the heritability of FA is still under debate. The majority of asymmetry research has found that the heritability of FA is low, although there have been a few studies that have found significant heritability (cf. Hallgrímsson 1998; Gangestad and Thornhill 1999; and Leamy and Klingenberg 2005). Nevertheless, through a wealth of scientific studies, mainly of animal and insect models, a strong connection between environmental stress and increased levels of FA has been found. It is the complexities of the nature of the developmental process and the abundance of possible contributing environmental factors that make the causes of fluctuating asymmetry elusive. As Naugler and Ludman (1996: 15) state: “the phenotypic expression of fluctuating asymmetry is presumably due to a complex series of interactions between the physical environment and the genetic constitution during ontogeny." That is, there is a mixture of both environmental and genetic influences on the levels of FA in an organism (Palmer *et al.* 1993; Leamy and Klingenberg 2005).

Fluctuating asymmetry studies are based on the premise that higher levels of FA in a trait indicate lower levels of developmental stability within an organism. Those individuals living in a stressful environment, or those that experience a specific stressful event during development, will have increased levels of FA (Palmer and Strobeck 1992; Palmer 1994). These levels of FA will increase with developmental time as bone is continually remodelled throughout ontogeny and in later life. FA will therefore accumulate in slower growing structures (Hallgrímsson 1998; Babbitt 2006), like the human skeleton. Differing levels of asymmetry in an individual could be due to either a stressful environment during development, an individual's inability to buffer against any environmental or genetic disturbances, or a mixture of both of these factors (Benderlioglu and Nelson 2004). Further, Optitz and Utkus (2001: 367) warn that "the same level of stress produces different degrees of fluctuating asymmetry in different individuals seems to indicate that the phenotypic outcome is modified by a variable ability to buffer the effect of environmental stresses." Some traits are more susceptible to developmental instability and, therefore, the level of FA may not be organism-wide but only detectable in specific traits (Møller and Swaddle 1997; Livshits *et al.* 1998; Gangestad and Thornhill 1999; DeLeon 2007). The more complex a trait is, the lower the FA (Livshits *et al.* 1998), so indices will have lower overall asymmetry than single traits.

The main focus of fluctuating asymmetry studies has been in the field of biology. Unlike directional asymmetry, the study of FA in past human populations is still in its infancy. Bioarchaeological studies of FA have included those of the cranium and mandible (Costa 1986; Hershkovitz *et al.* 1990; Türp *et al.* 1998; Storm and Knüsel 2005; Storm 2006; DeLeon 2007; Hoover and Matsumura 2008; Storm 2008), the teeth (Doyle and Johnston 1977; Perzigian 1977; Greene 1984; Hoover *et al.* 2005; Guatelli-Steinberg *et al.* 2006; Kegley and Hemingway 2007), and of multiple skeletal elements (Siegel *et al.* 1992; Hallgrímsson 1999). There are also a few studies which combine both DA and FA, including of the cranium (Hershkovitz *et al.* 1992; Gawlikowska *et al.* 2007), the humerus (Sladek *et al.* 2007), and multiple bones (Albert and Greene 1999; Kujanová *et al.* 2008). The following sections will consider these studies in greater length.

2.4 Asymmetry Trends throughout the Skeleton

Many studies, both clinical and bioarchaeological, have indicated that general trends exist in the patterning of asymmetries throughout the human skeleton. In general, the cranium has been found to be a normally asymmetric structure (Woo 1931; Trinkaus 1978; Skinner *et al.* 1989; Cohen 1995). A majority of cranial asymmetry can be associated with the lateral dominance of the brain (Pirttiniemi and Kantomaa 1992; Steele 1998) and intrinsic factors such as positioning of the head during early development and the birth process, which causes positional head deformity, torticollis, or other developmental abnormalities such as premature cranial synostosis (Skinner *et al.* 1989; Douglas 1991; Pirttiniemi and Kantomaa 1992; Cohen and MacLean 2000; Storm and Knüsel 2005; Storm 2008). Lateral dominance of the brain is reflected in the left occipital, the right frontal, and the left temporal lobe being larger (Woo 1931;

Trenouth 1985; Bradshaw 1988; Steele 1998). Further, the majority of bilateral traits in the calvarium and cranial base have been found to be right-side dominant (Woo 1931; Glassman and Bass 1986; Hershkovitz *et al.* 1992; Gawlikowska *et al.* 2007). However, there is suggestion that the occipital condyles may be antisymmetric, as Febbo *et al.* (1992) found that, although there was considerable asymmetry in these structures, there was no overall side dominance. For bilateral measurements of the viscerocranium, most have been found to favour symmetry over asymmetry, especially for those closer to the midline (Trenouth 1985; Hershkovitz *et al.* 1990; DeLeon 2007; Gawlikowska *et al.* 2007). When asymmetric, facial traits as a whole tend to be left-sided. However, when split into upper and lower halves, upper facial measurements tend to be right-sided, while lower measurements are left-sided (Trenouth 1985; Hershkovitz *et al.* 1992; Pirttiniemi and Kantomaa 1992). Similarly, studies of the mandible have found an overall left-sidedness in both length and in measurements of the rami (Pirttiniemi and Kantomaa 1992; Huggare and Houghton 1995; Türp *et al.* 1998).

The upper limb has had by far the most attention in asymmetry studies, especially in relation to hand preference and biomechanics. Unlike the lower limbs, the upper limbs are not restricted in function and are available for a wide variety of bilateral movements. Many studies have demonstrated that the upper limb is more asymmetrical than the lower limb, with almost all measurements favouring the right side (Schultz 1937; Latimer and Lowrance 1965; Pande and Singh 1971; Ruff and Jones 1981; Steele and Mays 1995; Sansibano-Collilieux and Morello 1996; Čuk *et al.* 2001; Auerbach and Ruff 2006). One study, however, found that FA in was more frequent in the lower limb (Kujanová *et al.* 2008). Debate still continues of whether asymmetry in the upper limb, especially the humerus, is due to an inherent genetic disposition, biomechanical influences due to hand preference, or environmental stress during ontogeny. It is likely that the aetiology of upper limb asymmetry is due to a complex mixture of all of these factors.

The humerus is the most asymmetric of the long bones of the upper limb and is significantly right-side dominant in almost all traits (Schultz 1937; Latimer and Lowrance 1965; Stirland 1993b; Huggare and Houghton 1995; Steele and Mays 1995; Sansibano-Collilieux and Morello 1996; Wilczak 1998; Tanaka 1999; Auerbach and Ruff 2006; Auerbach and Raxter 2008; Kujanová *et al.* 2008). Like the humerus, there is strong right-side dominance in the radius (Schultz 1937; Latimer and Lowrance 1965; Steele and Mays 1995; Sansibano-Collilieux and Morello 1996; Auerbach and Ruff 2006; Kujanová *et al.* 2008), ulna (Latimer and Lowrance 1965; Huggare and Houghton 1995; Steele and Mays 1995; Sansibano-Collilieux and Morello 1996; Kujanová *et al.* 2008), scapula (Latimer and Lowrance 1965; Kujanová *et al.* 2008), and the hand (Garn *et al.* 1976; Plato *et al.* 1980; Lazenby 1994; Roy *et al.* 1994; Steele 2000b; Mays 2002).

Unlike the long bones of the upper limb, the clavicle and the *os coxae* have been found to have more complex asymmetries. Although the clavicle is known to be right-side dominant, due to the biomechanical function of this structure, this dominance is reflected in the length being shorter and the diameter greater on the dominant side (Schultz 1937; Huggare and Houghton 1995; Mays *et al.* 1999; Steele 2000b; Auerbach and Raxter 2008; Kujanová *et al.* 2008). Likewise, the pelvis has been found to have differing asymmetries. The sacral alae were found to be left-sided (Plochocki 2002), while the *os coxae* was found to favour the right (Latimer and Lowrance 1965).

There have been many skeletal studies of directional asymmetry of the upper limb, especially in connection with handedness. For instance, Mays *et al*. (1999) found there was a direct link between activity patterns and the directional asymmetry of the clavicle. They demonstrated that the claviculae were longer on the left side, while on the right side there were larger midshafts and stronger ligamentous attachments. They concluded that the shortened nature of the right was an adaptation to greater loads being placed on the dominant (right) side. Blackburn and Knüsel (2006) found that in a living population the epicondyles of the humerus were significantly more asymmetric in active rather than non-active individuals. They also found that in a living population, the epicondyles of the humerus were only 68% effective in predicting handedness and that although the majority of right-handers were right-side dominant for epicondylar dimensions, some right-handers were left-side dominant and *vice versa*. Similarly, Selvaraj *et al.* (1998) classified handedness 89% of the time using measurements of the intertubercular sulcus, and Schulter-Ellis (1980) found that upper limb and scapula provided good evidence of handedness, with the greater degrees of asymmetry being in the dominant upper limb. However, studies of the hand suggest that handedness is not the only reason for right-side dominance in the upper limb. For instance, the right second metacarpal was found to be larger on the right side regardless of the individual's handedness (Garn *et al.* 1976; Plato *et al.* 1980) and non-manual workers were less right-side biased (Mays 2002).

Asymmetries in the lower limb are less well understood and are more complex than those in the upper limb. Studies of the lower limb have found contradictory evidence for overall side dominance. This may be due to the fact that the lower limb is not as asymmetrical as the upper limb, making any side differences subtle. The majority of femoral studies indicate that this structure is either primarily symmetrical in length and diameter measurements (Stirland 1993a, b; Čuk *et al.* 2001) or that there is slight left-side dominance (Schultz 1937; Latimer and Lowrance 1965; Ruff and Hayes 1983). However, one study did find right-sided asymmetry (Sansibano-Collilieux and Morello 1996). The proximal and distal ends of the femur, on the other hand, have a mixture of dominance. The proximal femur has been found to be either symmetrical (Rao *et al.* 2000), left-sided (Plochocki 2004), or right-sided (Auerbach and Ruff 2006; Kujanová *et al.* 2008), while the distal end has been found to be either right-sided (Kujanová *et al.* 2008) or symmetrical (Plochocki 2004; Auerbach and Ruff 2006). Studies of the tibia have also been contradictory, in that some found traits to be either left- (Schultz 1937; Latimer and Lowrance 1965) or right-sided (Huggare and Houghton 1995; Sansibano-Collilieux and Morello 1996). For articular measurements of the tibia, Plochocki (2004) found that the proximal end was symmetrical, while the distal end was right-side dominant.

There are many studies of the lower limb in connection with handedness and biomechanics. Many studies suggest that there is cross-symmetry of the upper and lower limbs (Auerbach and Ruff 2006)—that is, the right upper limb is dominant while the left lower limb is dominant. For instance, Plochocki (2002) concluded that the directional asymmetry observed in the sacrum was due to the use of the right upper limb for the majority of activities, which results in greater loading of the left lower limb and trunk. On the other hand, Čuk *et al.* (2001) found that the left femur was more developed in both right and left-handed individuals, indicating that handedness does not reflect lower limb asymmetry. However, they did find that for DA, lower limb dominance can be measured from the tibia, which has an opposite dominance to the handed upper limb. In a further study, Dane *et al.* (2001) found that in right-handed men, the left lower limb had significantly more bone mineral density and *vice versa*, although women were found to be symmetrical with no significant correlations with handedness. Similarly, Yang *et al.* (1997) found that there was no dominance in bone mineral density (BMD) for the proximal femur in women, and Maupas *et al.* (1999) and Maupas *et al.* (2002) found that although most people are right-footed, asymmetric activities in the knee are not related to lateralities. These contradictions may be explained by Sadeghi *et al.*'s (2000) study, which found that the dominant lower limb, usually on the right side, is used for mobilizing and manipulation, while the non-dominant is used for support. They suggest this is due to the right side of the brain controlling manipulation tasks. Although there was dominance in use of the lower limb, the separate functions of each side made it difficult to tell how asymmetry in gait is affected by lower limb dominance.

2.5 The Main Causes of Asymmetry

2.5.1 Genetic Influences on Asymmetry

Although still not fully understood, it can be assumed that there is at least some degree of genetic influence contributing to the total amount of asymmetry within an organism. Five main genetic causes of asymmetry have been established: the loss of variation in genes, the amount of protein heterozygosity, mutant genes disrupting the genome, directional selection either from evolutionary adaptation or sexual selection, and the disruption of co-adapted gene complexes through hybridisation (Møller and Swaddle 1997). Both animal and human studies have consistently demonstrated that the loss of variation in genes due to inbreeding increases the chances of and levels of asymmetry (Clarke *et al.* 1986; Livshits and Kobyliansky 1991; Mazzi *et al.* 2002). However, there have been contradictory studies of how heterozygosity affects the levels of asymmetry. The majority of studies have demonstrated that with the loss of heterozygosity there is an increase in the levels of fluctuating asymmetry. The lower level of homozygosity is thought to increase the buffering ability of an organism against environmental insult, and thus result in low levels of asymmetry. Further, Naugler and Ludman (1996: 18) found that "individuals that received a large number of deleterious recessive alleles (a high liability) would as a consequence be less symmetrical, thus producing a measurable heritability in fluctuating asymmetry." However, a few studies have found no connection between homozygosity and increased asymmetry (Palmer and Strobeck 1986; Livshits and Kobyliansky 1991; Palmer and Strobeck 1992; Hutchison and Cheverud 1995; Møller and Swaddle 1997). For instance, Livshits and Smouse (1993) could not find a connection between heterozygosity and FA in their study of a living Israeli population.

One of the better understood genetic causes of asymmetry is that of mutant genes. The most common re-occurring physical change resulting from congenital conditions is an increase in the levels of asymmetry. For instance, congenital conditions that have been associated with high levels of asymmetry are dwarfism, Down's syndrome (Trisomy 21), Warskany's syndrome (Trisomy 8), and cat cry syndrome (Deletion 5p), fragile X syndrome, foetal alcohol syndrome, and syndromes that feature craniosynostoses, muscular torticollis, cleft-lip/palate, club foot, congenital dislocations, and mental retardation (Barden 1980; Skinner *et al.* 1989; Livshits and Kobyliansky 1991; Kieser 1992; Cohen 1995; Naugler and Ludman 1996; Jones 1997; Thornhill and Møller 1997; Aufderheide and Rodríguez-Martin 1998; Cohen and MacLean 2000; Opitz and Utkus 2001; Roberts *et al.* 2004; Storm and Knüsel 2005; Storm 2008). The higher levels of asymmetry found in connection with various congenital conditions can be a reflection of either a predisposition to a specific genetic disorder that produces an increase in the susceptibility to FA, or it can result from the breakdown of developmental stability due to environmental stress which contributes to the expression of a disorder (Naugler and Ludman 1996).

Studies on the heritability of asymmetric traits have produced contradictory results, as some indicate that there is a low heritability of a genetic basis of both FA and DA, while some indicate significant heritability (cf. Graham *et al.* 1993; Palmer 1994; Møller and Thornhill 1997; Graham *et al.* 1998; Gangestad and Thornhill 1999; Leamy and Klingenberg 2005). Heritability of FA has been found in families with histories of developmental or genetic conditions, even in the absence of environmental stress (Opitz and Utkus 2001). In a recent study by Sengupta and Karmakar (2007) on familial relationships of 14 morphometric traits in a population from West Bengal found that there were significant correlations between parent and offspring and similar asymmetric traits, indicating heritability. However, their study also demonstrated that although some degree of asymmetry is inherited, it is not X-linked. They further concluded that FA and DA in the upper extremities had lower heritability than asymmetry in the lower limbs, which indicates that the upper limbs are more influenced by environmental factors such as biomechanics than genetic factors. On the other hand, Livshits and Kobyliansky's (1991) study of nuclear families found no relationship between the variation in fluctuating asymmetry and any genetic factors. They concluded that the explanation for the existence of asymmetry can be only due to environmental factors. Dibennardo and Ballit (1978) also found no relation with fluctuating asymmetry in children's teeth and inbreeding.

2.5.2 Human Laterality and Biomechanics

Biomechanical influence on bone directional asymmetry is perhaps the most commonly studied form of asymmetry due to its association with human laterality. The origins and causes of human lateralities, especially hand preferences, are still under debate. Human lateralities are thought to be due to either genetic influences or that they are initiated by the biomechanical, developmental, and/or cultural environments. It is thought that the lateralisation of the brain influences the direction of postcranial laterality in humans, with the left hemisphere controlling both language and skilled manual activities, especially manipulation. Precision movements of the right hand and foot are thus controlled by the left hemisphere. With such an understanding, evidence of right-handedness in the past can be found with the advent of tool-making, where the non-dominant hand is used to stabilize, while the dominant hand is used to shape the implement (Frost 1980; Holloway and De La Costelareymondie 1982; Spennemann 1985; Bradshaw 1988; Steele 1998; Harris 2000; Carey *et al.* 2001; Steele 2002; Steele and Uomini 2005). Similarly, various studies have connected bilateral activity to asymmetry, finding that most individuals usually exhibit directional asymmetry due to activity as increased size of the dominant side (Nilsson and Westlin 1971; Jones *et al.* 1977; Schulter-Ellis 1980; Ruff and Hayes 1983; Stirland 1993a, 1993b; Ruff *et al.* 1994; Steele and Mays 1995; Larsen 1997; Wilczak 1998; Knüsel 2000).

2.5.2.1 Evolutionary Origins of Handedness

The origins of handedness are still under debate. Evidence from non-human primate studies have been conflicting as to whether the origins of handedness began early in human evolution, or if it was already established prior to the advent of the genus *Homo*. Some studies have demonstrated that non-human primates do not have a hand preference during activities such as throwing and tool use (Bradshaw 1988; McGrew and Marchant 1992; Morbeck *et al.* 1994; Marchant and McGrew 1996; Annett 2002; Steele 2002), and therefore indicate that hand preference is uniquely human. Skeletally, Schultz (1937) found that non-human primates have less asymmetry in their upper limbs than *Homo*, but are similar in asymmetry in the lower limb. Conversely, other researchers have found that hand preference does exist in non-human primates, indicating that handedness may have been established before the advent of hominids (Falk *et al.* 1988; Hopkins *et al.* 1993; Westergaard and Suomi 1996; Steele 2002). However, when studies have found non-human primate handedness, it is usually weak and not at the population level. It has been argued that it is this population-level hand preference that distinguishes humans from non-humans (Steele and Uomini 2005). It is also thought that the advent of bipedality was a major contributor to population-level asymmetry, as it freed the upper limbs to specialise in bilateral activities. Furthermore, although cerebral asymmetries are thought to have been continuous through primate evolution, the incidence and extent of directional handedness has increased with the advent of the larger brain in hominids (Steele 1998, 2002).

Today, it is known that the majority of individuals are right- handed and footed. Estimates for left-handed individuals within a population vary from 1-40% (De Agostini *et al.* 1997; Kang and Harris 2000; Steele 2000b; Annett 2002), with males more likely to be left-handed than females (Spiegler and Yenikomshian 1983; Steele 2000b; Gorlin 2001). Similarly, right-footedness seems to be dominant at the population level, with estimates between 80-90% of the population (Kang and Harris 2000; Carey *et al.* 2001). The prevalence of handedness within a population depends on how that population is surveyed. Studies based on handwriting or perceived handedness indicate the average left-handed prevalence is about 8%, but those based on skill and strength tests suggest this is closer to 15% (Steele and Mays 1995). For the analysis of handedness in skeletal material, the prevalence is more likely that of the second estimate, as any directional asymmetry affecting the skeleton is more likely to be influenced by hand strength and manipulative ability, rather than by which hand is used for writing. For instance, Steele and Mays (1995) found that prevalence of right directional asymmetry in the humerus in Wharram Percy, a medieval population from England, was near 15% of the population, which is similar to modern handedness studies that defined handedness based on strength and skill tests.

2.5.2.2 Genetic Causation of Handedness

The principal genetic argument for handedness is Marian Annett's "Right Shift Theory," which states that the genetic basis for handedness can be demonstrated by a Right/Left genotype. Combinations of specific right and left alleles for handedness—with Right (R) dominant and Left (L) recessive—are why there is a diverse level of handedness in the population. There are strong right-handers with RR alleles, strong left-handers with LL alleles, and those who have weak handedness or who are ambidextrous with RL alleles (Annett 2002). The genetic argument for the cause of handedness has been demonstrated in many parent-offspring studies. For instance, researchers have found that left-handed parents are more likely to have left-handed children (Spiegler and Yenikomshian 1983; Saudino and McManus 1998; Gorlin 2001). However, Saudino and McManus's (1998) Colorado Adoption Project demonstrated that there were no familial trends in lateralisation of the hand, foot or eye as there were no associations between laterality and either the biological or adoptive parents. Although they did find that children of left-handed mothers were more than twice as likely to be left-handed as those of right-handed mothers. However, this was found not to be the case between fathers and their offspring (Spiegler and Yenikomshian 1983; Saudino and McManus1998). Although taken as evidence of the genetic inheritance of handedness, parent-offspring studies could also be argued to be a reflection of learned behaviour, or it could be a response to environmental pressures, such as the dominance of right-handed implements (for instance, door handles).

It is still unknown when in ontogeny right hand dominance is established. Research into foetal handedness has tried to resolve this debate, but evidence of both left- and right-side origins has been found (Pande and Singh 1971; Bagnall *et al.* 1982; Stirland 1993a; Steele and Mays 1995; Steele 2000a, 2000b; Woźniak and Bruska 2006). These opposing findings give evidence for both arguments of genetic and environmental causation. For instance, a number of studies have found that asymmetry is evident by the fourth foetal month and has a right-side bias, suggesting a genetic basis for handedness and not a later biomechanical adaptation to hand preferences or the presence of environmental disruptions during ontogeny (Schultz 1923; Stirland 1993a). On the other hand, some studies have found a left-side dominance and symmetry in foetal humeri, which suggests that right-side dominance is established later in development, and, therefore, is most likely due to the biomechanical environment (Bagnall *et al.* 1982; Steele and Mays 1995). For example, Gorlin (2001) demonstrated that infants use both hands intermittently and that handedness is not established until two to six years old.

2.5.2.3 Developmental Instability and Handedness

Handedness has also been argued to be due to developmental instabilities (Markow 1992; Yang *et al.* 1997). Yang *et al.* (1997) argued that variations in handedness are due to developmental instability during early foetal development. They stated that individuals with minor physical abnormalities and high levels of fluctuating asymmetry are more likely to have extreme expressions of handedness. Further, they found that left-handedness has a high association with reduced fitness, neurodevelopmental disorders, and neuroanatomical differences. Their research indicated that left-handers have fewer children, lower birth weights, late onset of puberty, more miscarriages, are at a higher risk to some diseases, more apt to have developmental disorders of the nervous system, have more accidents, and die at an earlier age. However, other researchers argued that this pathological theory of handedness is unfounded (Steele and Uomini 2005).

2.5.2.4 Cultural Influences and Handedness

It has been suggested that handedness is a learned behaviour, and therefore culturally influenced (Brackenridge 1981; Harris 2000). Handedness can be said to be a learned response to a child's observations of how their parents, siblings, friends, and strangers manipulate objects. A child will also learn how to hold and interact with objects from their parents and carers. For instance, a right-handed mother teaching her child to turn pages in a book or play with toys might unconsciously always place the child's right hand on the object because that is what she would do herself. In addition, in the past, left-handedness was looked down upon and shunned. Left-handed children were taught to use their right hands when writing and chastised when they used their left. Recent relaxation of such cultural pressures has seen a rise in prevalence of left-handed individuals over the past few generations (Brackenridge 1981; Spiegler and Yenikomshian 1983; Steele 2000b). For example, Brackenridge (1981) found that between 1932 and the 1970s left-handedness increased by 9% overall, with an increase in left-handers in Australia from 2% to 13.2% from the 1880s to 1969.

2.5.2.5 Mixed Causations and Handedness

Although the asymmetrical effects of human handedness have been argued to be separate from that of developmental instabilities and that handedness is mainly due to genetics and the biomechanical environment, all of these factors may contribute to the overall asymmetry of a structure. For instance, the effects of handedness may be in the opposite direction to that of the effects of developmental stabilities; as a result these factors can either balance each other out, lessen the expression of the asymmetry, or they could accentuate the direction of the asymmetry (Steele 2000). In his study, Knüsel (2000a) found little dominance overall in the humeri of individuals from a mass grave at the battlefield site of Towton. On closer examination these individuals' maximum humeral head diameters favoured the right side while the distal ends had no side differences. This, coupled with a similar patterning in cross-sectional data, indicated that there were differential loading patterns between the proximal and distal ends, which balanced the overall asymmetry. A possible explanation for this symmetry is that these combatants were engaged in two-handed activity, possibly archery (Rhodes and Knüsel 2005). Similarly, Stirland (1993a, 1993b) found that humeri from soldiers aboard the *Mary Rose* were more symmetrical, concluding that, like the Towton population, they were also engaged in strenuous activities requiring the use of both upper limbs. Furthermore, the degree of directional asymmetry may not be equal for left- and right-handed individuals. Schell *et al.* (1985) found that in a living adolescent population, when right- and left-handed individuals were analysed separately, right-handed individuals possessed a significant amount of asymmetry but left-handed individuals had no significant asymmetry.

2.5.3 Environmental Influences on Asymmetry

Environmental influences on developmental homeostasis are the most important factor in the study of fluctuating asymmetry (and to a certain extent directional asymmetry). As has been discussed above, any deviation from the normal environment requires adaptation on the part of the organism. During the adaptation process an organism under stress will expend energy, usually stored for maintaining developmental stability, to compensate for that stress. If there is a lack of energy to maintain homeostasis, then there is a breakdown in cell-to-cell interactions and fluctuating asymmetry results (Møller and Swaddle 1997; Nijhout and Davidowitz 2003). The greater the environmental variation, then higher levels of fluctuating asymmetry will result (Willmore *et al*. 2005). The environmental factors which have the potential to disrupt development are numerous; they include extreme temperature (Siegel *et al.* 1977; Mooney *et al.* 1985; Gest *et al.* 1986; Clarke 1993; Mpho *et al.* 2002; Polak *et al.* 2004), environmental pollution (Valentine and Soule 1973; Zakharov and Yablokov 1990; Markow 1992; Clarke 1993; Graham *et al.* 1993; Eeva *et al.* 2000; Mal *et al.* 2002; Sonne *et al.* 2005), season of birth (Benderliouglu and Nelson 2004), noise pollution (Mooney *et al.* 1985; Gest *et al.* 1986; Markow 1992), population density (Zakharov *et al.* 1991; Møller *et al.* 1995) and parasitic load (Møller 1992; Polak 1993).

The literature is replete with studies of the effects of environmental stresses on organisms. The majority of these studies concern animal and insect models for detection of environmental disturbances. For instance, Badyaev *et al.* (2000) studied the developmental reaction in shrews with the removal of vegetation. They found that fluctuating asymmetry increased dramatically in this stressed population and not in the control population which was from a normal enriched environment. Zakharov and Yablokov (1990) demonstrated that asymmetries in the skulls of Baltic grey seals increased after a period of heavy organchlorine pollution; and Gest *et al.* (1986) found that when laboratory rats were subjected to extreme temperatures or loud noise they had significantly increased fluctuating asymmetry in the femora lengths. A subsequent study conducted on shrews established that there was a definite connection between population density and fluctuating asymmetry. The shrews possessed the highest rates of asymmetry when the population reached its highest density (Zakharov *et al.* 1991).

The effects of environmental stress have also been found amongst human populations. For instance, the asymmetrical responses to environmental stress were tested on a modern Japanese sample population through the examination of the teeth of individuals who lived through the Second World War and those who were born afterwards. The study found that there were no significant differences in the level of asymmetries with reference to gestation age, birth weight nor prenatal stress; however, there were significant differences in the amount of asymmetry found between the dates of birth, with the most stressed group, the older war generation, with the greatest amount (Dibennardo and Ballit 1978). In a similar study, Albert and Greene (1999) found that epiphyseal fusion in two archaeological Nubian populations was significantly asymmetric in the early Christian population but not in the later period. In a follow up study of the same populations, DeLeon (2007) found that crania from the early Christian population were more asymmetric than the later period. Both studies concluded that the increased asymmetry in the early period reflected the archaeological and osteological evidence for a more stressful environment due to poor nutrition and a high parasite load.

Studies have also established that environmental stress can be a greater influence on both directional and fluctuating asymmetry than bimanual and unilateral activity. For instance, Sladek *et al.*'s (2007) analysis of DA and FA found that there were few biomechanical changes between late Eneolithic and early Bronze Age populations in external and cross-sectional measurements of the humerus. They did, however, find significant FA in male humeral length for both populations but not for females. Since they noted little difference in social and economic factors between their samples overall because there was minimal biomechanical change, they concluded that the asymmetry in male humeri must be due to environmental factors. In a study of mandibular condyles, asymmetry in these structures was found not to correlate with the amount of tooth wear. As the asymmetry did not seem to relate to mastication, it was argued to be due to environmental stress (Costa 1986). Furthermore, as studies of the femur have found this element to be more or less symmetrical attributed to the body's need to maintain a bipedal stance (Plochocki 2004; Auerbach and Ruff 2006), any deviation away from that symmetry is most likely a reflection of environmental stress.

2.5.4 Fitness and Health

Linked closely to environmental stress, an individual's fitness and health status have been associated with the amount of asymmetry within an individual and population. Those individuals with a low fitness or poor health will lack the resources to properly buffer against developmental disruptions caused by environmental stresses (Møller and Swaddle 1997; Gangestad and Thornhill 1999; Leamy and Klingenberg 2005). In the case of an individual's fitness, it has been found that the higher the asymmetry, the lower an individual's attractiveness and mating success. Studies have shown that attractiveness is directly related to the image of good health and that healthy genes are associated with the ability to buffer against environmental conditions, thus ensuring the reproductive success of symmetric individuals (Thornhill and Gangestad 1994; Perrett *et al.* 1999; Little *et al.* 2001). For instance, Jones *et al.* (2001) found that facial attractiveness was associated with a more symmetrical face and that this symmetry was perceived to be an indication of individual's good health status. A similar study was conducted on college students and found that the more symmetric an individual, the more sexual partners they had and the earlier they had their first sexual intercourse. The study also indicated that if an individual was more symmetrical, there was a perception from others that they benefited from good genes (Thornhill and Gangestad 1994). Reproductive success was also measured by Benderlioglu and Nelson (2004). In their study they found that there was a decrease in the level of asymmetry with the greater number of siblings an individual had. They argue that lower asymmetry levels in children may indicate that they had inherited their parent's ability to buffer against adverse environmental conditions.

Many factors have been found to connect an organism's health status and the level of their asymmetry. High levels of asymmetry have been found to be connected with premature birth (Livishits *et al.* 1988), maternal age (Markow 1992), diabetes (Kohn and Bennett 1986), nutritional stresses (Imasheva *et al.* 1999; Badyaev *et al.* 2000), small stature (Perzigian 1977; Siegel *et al.* 1992), increased body fat and weight (Manning 1995; Manning *et al.* 1997; Milne *et al.* 2003), congenital and developmental conditions (Barden 1980; Malina and Buschang 1984; Pirttiniemi and Kantomaa 1992;

Hoyme 1993; Cohen 1995; Churchill and Formicola 1997; Juhl *et al.* 2004), and disease rates (Livshits and Kobyliansky 1991; Markow 1992). For instance, in a foetal study Livshits and Kobyliansky (1991) found that after the factor of the developmental age of a foetus, disease rates had the highest correlation with high levels of fluctuating asymmetry. In one study of teeth, Perzigian (1977) found that in comparison to other archaeological populations, a population from Indian Knoll, Kentucky, had the highest levels of FA. These individuals were also found to have a higher prevalence of Harris lines, dental enamel hypoplasia, small statures, and high infant mortality. Further, Manning *et al.* (1997) found that the lower the resting metabolic rate, the lower an individual's asymmetry because the body has sufficient amounts of energy to maintain symmetry. A negative association with body weight and asymmetry has also been found. Research has demonstrated that the heavier an individual is and the higher the body mass index (BMI), the more that individual was found to be asymmetric, indicating that developmental stability decreases as weight increases (Manning 1995; Milne *et al.* 2003).

2.6 Individual Characteristics and the Effects on Asymmetry Levels

2.6.1 Sex

Many studies have examined the relationship between asymmetry and sexual dimorphism. Differences between the sexes in asymmetry may arise due to differing activities and activity levels, nutrition, hormonal levels, genetic predispositions (e.g. X-linked genes), and developmental and social environments. Human asymmetry studies have produced conflicting findings relating differences in asymmetry to sex. Some researchers have found no significant differences in directional and fluctuating asymmetry between the sexes (Trenouth 1985; Hershkovitz *et al.* 1992; Roy *et al.* 1994;

Steele and Mays 1995; Sansibano-Collilieux and Morello 1996; Mays *et al.* 1999; Plochocki 2002; Plochocki 2004; Blackburn and Knüsel 2006) while others have found significant differences between males and females (Schultz 1937; Perzigian 1977; Ruff and Jones 1981; Costa 1986; Wilczak 1998; Hallgrismsson 1999; Steele 2000b; Auerbach and Ruff 2006; Guatelli-Steinberg *et al.* 2006; Sladek *et al.* 2007; Auerbach and Raxter 2008). For instance, Hershkovitz *et al.* (1992) found that there were no significant differences between the sexes in DA nor FA, while in another similar study of fluctuating asymmetry Hershkovitz *et al.* (1990) found females to be less asymmetric than males. On the other hand, no significant differences in FA were found by Hallgrímsson (1999) in cranial measurements. For the mandible, Costa (1986) did not find any significant differences in directional asymmetry between the sexes in mandibular condyles. Further, Perzigian (1977) and Dibennardo and Ballit (1978) found no sex differences in FA in teeth, while Guatelli-Steinberg *et al.* (2006) found that females had a significantly greater amount than males. Also, no significant differences were found between the sexes in sacral measurements (Plochocki 2002).

In the upper limb, females have been found by some researchers to be more asymmetric than males (Schultz 1937; Steele 2000; Auerbach and Ruff 2006), while other studies found no such sex differences (Steele and Mays 1995; Sansibano-Collilieux and Morello 1996; Hallgrímsson 1999; Pomeroy and Zakrzewski 2009). For the clavicle, Auerbach and Ruff (2006) found no sex differences in length, but they did find males had higher midshaft asymmetry, while Mays *et al.* (1999) found no overall sex differences, except that there was more lateral curvature in the male clavicle. Males and females were found to differ in DA in the humerus, with males being more asymmetric (Ruff and Jones 1981; Wilczak 1998; Auerbach and Ruff 2006; Sladek *et al.* 2007), whereas females were found to be more asymmetric than males in the ulna (Kujanová *et al.* 2008). No significant differences were found by Roy *et al.* (1994) in the second metacarpal. However, Mays (2002) found that although females did not have significant DA in the second metacarpal, males were found to be asymmetric. He concludes that males appear to have been more sensitive to stress than females.

There were also conflicting findings for asymmetrical differences between males and females in the lower limbs. No significant differences were found in the lower limbs by Sansibano-Collilieux and Morello (1996), Hallgrímsson (1999), Auerbach and Ruff (2006) and Pomeroy and Zakrzewski, (2009), while Schultz (1937) found males to be more asymmetric than females and Ruff and Jones (1981) found the opposite to be true. For the femur, Dane *et al.* (2001) demonstrated that there were sex-linked differences in the bone mineral density of femora of living modern populations. They found females did not exhibit any side preference in mineral density but the males' density was greater on the left.

2.6.2 Age-at-Death

As discussed in Section 2.2, age-related fluctuations in asymmetry are to be expected. Both biomechanical adaptations to bone morphology and the effects of developmental noise are at their greatest during the growth period. These resulting asymmetries will increase and accumulate during ontogeny and in late adult life (Emlen *et al.* 1993; Palmer *et al.* 1993; Palmer 1994; Møller and Swaddle 1997; Hallgrímsson 1998, 1999; Klingenberg 2003; Auerbach and Ruff 2006; Ruff *et al.* 2006). Wilson and Manning (1996) found that there was a reduction in fluctuating asymmetry from 2-10 years of age, followed by an increase in adolescence from 11-15 years, peaking at 13 years for males and 14 for females. This was then followed by a reduction in FA after 15 years of age to a level that is maintained until the 18th years. They suggest that the higher levels of asymmetry in children is due to the rapid growth process, which makes it difficult for the individual's body to maintain symmetry, therefore, they accumulate asymmetry, and then correct for it later in adolescence. Hallgrímsson (1999) found that fluctuating asymmetry increased in post-cranial elements (although not significantly) and in cranial traits (where asymmetries significantly increased even into adulthood) with the age of the individual.

Similar age-related increases have also been found in directional asymmetry. For instance, DA was found to increase with age in the upper limb (Steele and Mays 1995; Chilibeck *et al.* 2000) and in humeral measurements (Trinkaus *et al.* 1994). However, some studies have found no relation to age and levels of either directional or fluctuating asymmetry. For example, no age-related differences were indicated in studies of the mandibular condyles (Costa 1986), teeth (Dibennardo and Ballit 1978; Guatelli-Steinberg *et al.* 2006), humeri (Blackburn and Knüsel 2006) and sacra (Plochocki 2002). In addition, Ruff and Jones (1981) found that there was a decrease in cross-sectional asymmetry with age for the humerus and tibia. It was also found that humeral asymmetry decreases with age in some studies (Ruff and Jones 1981; Stirland 1993a, 1993b).

2.6.3 Socio-Economic Influences on Asymmetry

It is postulated that an individual's social and economic environment will affect the prevalence and extent of asymmetry. Social and economic situations of individuals are suspected to have a large affect on the amount of fluctuating asymmetry because those with higher social status and wealth will have better access to good nutrition, health care, and improved living conditions and will thus show only small amounts of asymmetry. Those from poorer/low status backgrounds should exhibit higher levels of asymmetry as they will have diminished living conditions, lack access to adequate nutrition and health care, possess a higher risk and prevalence of disease, and are subjected to harder labour. There are a few human asymmetry studies that focus on socio-economic differences between populations. One study by Kujanová *et al.* (2008) found that levels of both DA and FA were 70% less in their medieval sample when compared to a modern 1930s sample. The modern sample was known to be of a low social status and therefore under considerable environmental stress due to poor nutrition and unhealthy living conditions. Similarly, Guatelli-Steinberg *et al.* (2006) found higher levels of asymmetry in teeth of a modern Gullah population when compared to a related archaeological population. Historical and archaeological evidence indicated that the modern population suffered greater environmental stress as they were known to suffer extreme poverty, were subjected to harder labour, had high infant mortality, and a high disease rate. Hoover and Matsumura (2008) found that, although historically the incipient agriculturists from the Late/Final Jomon period in Japan differed greatly from the earlier Middle Jomon population in the amount of nutritional resources available (the later being the least stressed), the effects of social stratification on access to these resources may have caused the higher developmental instability found in the Middle Jomon population.

2.7 Summary

The exact aetiology of directional or fluctuating asymmetry within a trait may never be known. During ontogeny and adulthood the body reacts to buffer against developmental noise while it acts to adapt to biomechanical stresses placed on the skeleton. Both directional and fluctuating asymmetry have been found to accurately measure the body's reaction to these factors. In humans, it is likely that any resulting asymmetry is due to a complex mixture of genetic influences, behavioural laterality and biomechanical stress, environmental stress, and the health status of an individual. Although results from measuring asymmetry alone may not be able to resolve the specific causes of an asymmetry, it may be possible to decipher possible causes by comparing the levels of asymmetry in populations with differing activities, social organisations, health, and environment inferred from historical, archaeological and osteological evidence. This is what the present dissertation sets out to explore.

Chapter Three

Contextualizing the Material

3.1 Introduction

As the levels of population asymmetry are heavily influenced by the developmental environment and physical activity of the individual, it is essential to understand the socioeconomic and environmental background of the sample from which they came. The most important part of any osteological research is to connect the osseous 'material' analysed to that of the lives of individuals in the past. This is the most vital step in the understanding of human health and development. Without an understanding of the environs of the populations under examination, the causes and effects of developmental instabilities and fluctuating asymmetries cannot be understood. Section 3.2 provides a brief socio-economic and environmental historical overview of the middle Anglo-Saxon period to post-Medieval England. Each time period is divided into separate discussions of rural and urban environments, as there are great differences in the socio-economic and environmental backgrounds of these two settings within a single period and diachronically between periods. Section 3.3 presents the samples included in this study with a brief discussion of each archaeological site's specific historical, archaeological and osteological background.

3.2 A Socio-Economic and Environmental History

Urban and rural environments have been separated within the discussion of each time period as they have distinct socio-economic and environmental backgrounds, although they were interdependent. Here, the definition of urban is defined as being a centre with a permanent population numbering in the hundreds who made a living from non-agricultural and diversified occupations; as having a range of institutions, including a mint, market, and local government; as having planned street system; as having a distinct area of rural lands providing it with food; as having a complex religious organization; and which had a complex social organization that differs from the surrounding rural area (Russo 1998; Reynolds 1999; Dyer 2003).

3.2.1 Middle to Late Anglo-Saxon (Early Medieval) England (600-1050)

3.2.1.1 General Background

With the end of occupation and withdrawal of the Roman military in the late 4th century, the population of England experienced a drastic reduction from the estimated five million people to between 2.2 and 2.5 million by the writing of the Doomsday Book in 1086, of which ten percent lived in urban centres. From 6th to the 10th century, the population lived mainly in small scattered open field farming settlements consisting of five households and a predominately agricultural economy, a trend which continued until the 18th century. The main specialised crafts were woodworking, weaving and metalworking (Laing and Laing 1979; Hooke 1989; Dyer 2003). The population's diet consisted mainly of grains (wheat, barley, oats), peas, beans, corn, meat (sheep, pigs, cattle), and fish (Dyer 2003).

The Viking incursions began in the north of England in 789-95 and by 896 they occupied many regions throughout England, with the North under their rule and York as their capital. Initially, this was a time of social disruption as the Scandinavians targeted the wealthy and as they themselves settled in the countryside. Although these settlers were the 'conquering' people, they only took control over what was already instituted, leaving social and agricultural systems as they were. With them, they brought better trade networks, town expansion, and, indirectly, the unification of a central state and an economic boom. The Anglo-Scandinavians also brought forward a change from an exchange economy to one heavily dependent on minting and the use of coinage in all transactions. By the 10th century, England enters its first 'industrial' revolution. There was an increase in trade connections; urban growth; metal, bone, stone, wood and leatherworking increased; pottery, weaving, and textile production increases; and food sources and varieties increased (Dyer 2003).

Although the health of those living in urban centres would have been disadvantaged by poor living conditions and mounting pollution, most of the population of England was still living in rural settlements, thus general health during the Anglo-Saxon period was better than that of the Roman and the following Medieval periods. Skeletal evidence further suggests that this was the case, as many conditions like anaemia, trauma, dental disease, and joint disease had decreased (Roberts and Cox 2003). The average stature of the population had also increased (Schweich 2005). On the other hand, and maybe reflecting the trend of urban development, there was an increase in infectious and neoplastic diseases and an increase in prevalence of congenital conditions evident in urban centres during this period (Roberts and Cox 2003).

3.2.1.2 Rural Life

Beginning in the 10th century, people began to settle in villages composed of between 12 and 60 compact households with surrounding open agricultural field systems (Dyer 2003). The villages were usually founded along trade routes, but there were also smaller villages located on marginal land and small satellites to a larger village. The field system and clustered housing were linked to the lord's house and the church, which would have been the centre of the village life, having social and administrative influence over the community (Postan 1972).

Social status during this period was based mainly on birth, wealth and occupation. The great estates—owned by kings, bishops, monasteries and nobles—were as large as 10 miles across and were maintained though taxes and rents, consisting of a proportion of the foodstuffs produced on their land. These nobles were at the top of the local social system; they would have held governmental positions, were born to the title, and worth 1200 shillings or more. They were followed by the independent peasant (*geneat*) defined as being freemen who were worth 200 shillings, having a large land holding that was passed down though the family, and owing less labour service to the lord, enabling them to supplement their income selling their crops and wares. Although the lord would have had control over most of the peasant's life, there were manorial courts run by the villagers and which acted on the behalf of the village as a whole. However, these were overseen by the lord or his representative (Postan 1972; Laing and Laing 1979; Reynolds 1999).

The independent peasants were followed in the social hierarchy by the peasant owning a 30-acre holding (*yaldland*), a *ceorl*, who were also free but were required to work on the main estate two to three days a week and to pay a higher rent than the *geneat*. The common holding included a house of a timber 15 by 30 feet with a barn and out-building and 15 acres of cultivated land, with access to common land, which would have been economically sustainable for the family. The lowest of the peasant class were the small holders (*cosetla*) or the hired worker. Their holdings would have been too small for *cosetla* to live on and thus they would have had to depend on income from being hired labour. At the bottom of the social structure would have been servants and manual labourers (Dyer 2003).

3.2.1.3 Urban Life

The Doomsday book indicates that there were more than one hundred towns in England at the time of its writing. The number and growth of market towns was further advanced in the 9^{th} to 10^{th} century by Edward the Elder in his Law Code and in the 10^{th} century by King Athelstan in his Second Code, which made it an offence to sell or buy goods over 20 pence outside a market town and that all trading was to take place within the town (Hill 1988). A hierarchy of towns existed, with London being the most populated and influential, followed by York, Winchester, Norwich, and then Lincoln. The social system consisted of the elite officials, clergy and aristocrats on the top tier, followed by the craft and tradesmen, with the servant at the bottom. Occupations included food processing, woodworking, leatherworking, potters, artisans, smithies, glassware producers, textile workers, and tradesmen (Dyer 2003).

Life in the urban centre may have had its advantages in freedom and economic advancements, but it also had many downfalls. The density of houses constantly increased, towns were vulnerable to fires as everything was built of wood, and the pollution at many times would have been unbearable. During the Anglo-Scandinavian period, there was an expansion of the black rat population in England, with rats a commonplace in urban centres (Schofield and Vince 1994), which would later become an essential factor in one of the most devastating events in history, the Black Plague.

Due to extensive excavations, one of the best examples of the living conditions and the pollution of urban centres during this period comes from York. During this period, York was flourishing and could boast to be one of the largest and most influential cities in England, and which had a powerful economy. However, York was not a pleasant place to live. In Coppergate, one of the main districts in York, the average house size was only 14 by 25 feet (Dyer 2003). There was a high amount of rubbish piled everywhere, with rats and flies in quantity, and human fleas and lice a common problem. People lived in close proximity to animals that carried their own parasites, beetles and weevils were found in most stored foodstuff, flooding was commonplace, and houses were mixed with industrial premises. The River Foss was used as a rubbish tip and for drinking water. The other main river, the Ouse, had become so polluted that certain species of fish disappeared from its waters (Laing and Laing 1979; Addyman 1989; Kenward and Hall 1995; Dyer 2003). The water supply not only came from these polluted rivers, people would also collect water run-off from roofs and have backyard pits and wells. Many of the wells would have been contaminated by nearby rubbish pits and latrines. Around 90% of the coprolites recovered from such backyard pits have been found to have intestinal parasites (Addyman 1989; Kenward and Hall 1995).

3.2.2 Early Medieval England (1050-1300)

3.2.2.1 General Background

The Norman invasion and English defeat of 1066 had a dramatic effect on the peoples of the land. The years from 1066 to 1086 saw the largest redistribution of both rural and urban property in all of English history. Societal and economic change was quick, with a division being made between the social elite and the commoner. King Alfred had stated that the new social structure of England could be broken into "those who fight, those who pray, and those who work" (Dyer 2003: 72). On closer examination, the new structure was much more complex. The old aristocracy found itself pushed out or indebted, with most demoted to being the new rich peasantry. At the top was the new aristocracy, which were defined as those who gained their status though their birthright, legal status, function, wealth and lifestyle (these positions included the king, earl, thegn, count, baron, sheriff, viscount, and knights), consisting of Norman supporters of William, a high status lay population, and ecclesiastics (Dyer 2003).

Soon after the Norman invasion, England saw a strengthening of the state and economic growth due to increase in agricultural productivity, agricultural technological advancement, and an increase in industry. Settlements and towns increased in size and number across the country (Dyer 2003). By 1340 the population of England was estimated to have been approximately 5 to 6 million people. The population density of the country soon led to an imbalance between the resources available and the need and demand of the populace. Such an imbalance left the country unable to cope with disasters or epidemics (Schofield and Vince 1994).

3.2.2.2 Rural Life

The social structure of the rural communities was also affected by the Norman invasion and settlements. With the displacement of the top tiers of society, the lower levels grew in number and changed in definition. Social differentiation was now based on knights' service and tenure. The larger structure consisted of a lord of the manor, then the free tenants and serfs. The core social structure of the rural communities consisted mainly of small nuclear families. Rural life became harder during this time as the lords and state demanded higher rents and taxes and due to the disappearance of slave populations (Dyer 2003).

According to estimates from the Doomsday Book, it is suggested that 40% of rural population consisted of peasant tenants called *villeins*. These individuals had an average of three oxen with landholding of 15-30 acres, from which it would have been sufficient to make a living (Dyer 2003). They could afford improved housing and they had more children than those of lower status, averaging 5.1 children per family (Dyer 1989, 2003). According to the Royal court, although the villein would have held his own land and possessions in the 12th and 13th centuries, the lord's control over the villein would have been absolute. The courts were almost always in favour of the Lord and, thus, the villein could not sell his lands without consent nor complain about increased rents. In practice, though, this is not always the case as the smaller manorial courts followed local customs and usually dictated that the peasant could inherit his land and that his taxes and services to the lord were fixed (Harvey 1989).

Below the villeins came the borders and cottars, who made up 30% of the rural population. These individuals were less fortunate and could only afford 3-5 acres of land. The difference in the size of the land-holding became the widening social and economic gap between the *villeins* and cottars. As the cottar only had a small amount of land with a modest house and perhaps a small garden, it would not have been enough to sustain a family, forcing many to become cheap hired labourers. Due to their lower status, the cottars could only provide for themselves and their average of 1.8 children with a diet that was just enough to live on, having little to no variety. As this was the case, many of these peasants gave up their small holdings to become tradesmen or hired hands. Many children were sent into indentured servitude at about 12 years old to supply the family with extra money (Dyer 2003).

The rural staple diet consisted of bread and porridge, ale, and garden vegetables. The better-off peasant supplemented their diet with meat (pig, cow, poultry, and wild game), dairy and eggs, malt and a wider variety of garden vegetables. The wealthy peasant could also afford to have fish, shellfish, fruit and sugar on their tables (Dyer 1989; Roberts and Cox 2003). Peasant housing mainly consisted of a simple longhouse built of cruck and timber with daub or chalk walling. The buildings were often in need of repair and sometimes the whole building would be moved to another position on the peasant's land. The poorest of the peasants lived in 'peasant cots,' which were circular or rectangular buildings, shared with their animals, on a small area of land situated at the edge of the village green. The more affluent peasant usually had a house used for domestic purposes only and barns and out-buildings for agricultural proposes (Wrathmell 1989).

Although mainly agricultural, with the boom in the market economy, new craft specialisations began to open up for the rural peasant. These new trades included potters, weavers, smiths, leatherworkers, tailors, builders, and brewers (the last being mostly women). Some made a living through making and selling products used in everyday rural environments, like clothing and agricultural tools. In some areas mining became an important occupation for rural peasants. There were also a few peasants that made their living from buying and selling land, which at the early part of this period would have been lucrative due to high demand (Dyer 2003). By the 13th century, there was such a hunger for land that people stood in long lines seeking to buy an available plot, which had declined in average size (Postan 1972).

3.2.2.3 Urban Life

Although less affected by the Norman invasion, towns faced some change through the redistribution of property of the old aristocracy and elite officials. In the beginning of this period, it was mainly coastal towns that prospered, due to the new influx of movement between the continent and England. By 1300 it is estimated that there were 830 towns in England. At the time of the Norman invasion approximately 10% of the population was living in urban centres, rising to one fifth by 1300. Many young peasants, especially women, moved from the countryside to the towns in hope of finding work and new form of economic and social freedom removed from the restrictions of the landlord (Dyer 2003). Urban development and founding of new market towns was at its peak during the economic growth of the 12th and 13th century (Platt 1978). At the centre of the town was the market and church. The rich usually lived in the suburbs, although living in the city centre was sought after by many rich merchants. The poor, on the other hand, lived in cramped quarters in the manufacturing/trade/craft areas and the town's outskirts. In all areas of the town overcrowding was an ever-present problem, especially in the smaller towns. This forced people to live not only in close proximity to other people, but also to animals. As with the Anglo-Saxon period, during this time, all aspects of industry within the town created pollution. It was not until the late 14th century that authorities in some urban centres began to take action to clean the town though refuse disposal and a piped-in water supply (Dyer 2003).

Socially, the urban centres were very different from that of the country. Here social differentiation was based on a monetary economy. The merchants, citizens and burgesses were at the top of society. The merchant class marked their place in the social ladder through successful business and trade ventures. These three groups of individuals were the wealthiest in the town and usually were involved in governing and money-lending (Kermode 1998; Dyer 2003). Just below them were the craftsmen, those individuals who made up the manufacturing community engaging in specialized skilled work, including those working in the leather, textile, metal and wood industries. Within this group were also those employed in the food and drink trade, which made up most of the employment in the town (Dyer 2003). The most esteemed occupations were the founder, hosier, tailor, and stringer (Dyer 1989).

Wealth in towns was not equally distributed, with most of it held by merchant and skilled workers and with the majority of the population being of modest means or in poverty (Dyer 1989). At the bottom of society were the very poor, those with no stable income, some of whom had criminal occupations, including prostitution. Many would have been beggars who lived on handouts from wealthy citizens and the monasteries. Above them came the servants who worked for room and board in the household they served. Servants accounted for 20-30% of the urban tax payers, making it the most common urban vocation. This was usually the first occupation of individuals who moved into the cities from the countryside. At the same level, and also working for room and board, were the apprentices. Above the apprentice came the labourers who had a rented accommodation and who were engaged in unskilled, ill-paid, short-time work (Dyer 2003).

Living conditions in urban centres were still very poor. The average city's population density was estimated to have been approximately 29 people per acre within the walls, growing to 81 per acre at its centre (Dyer 1989). Although there were some improvements, there was an increase in pollution levels and there were few improvements in sanitary conditions. All levels of society would have been affected. For instance, in York, there is evidence that the main river and source of drinking water, the Ouse, which suffered pollution during the previous period, had been contaminated by heavy metals by at least the early 13th century, mainly from lead mining upstream (Hudson-Edwards and Macklin 1999). Streets were filled with rubbish; privies were not regularly emptied or were positioned over running water so waste ran into open drains; animal manure was left on the street; butchers' waste ran into the street and rivers; flies swarmed on the meat being sold; dead animals were left where they fell; leather makers, tanners and dyers let their waste products run into the rivers and streets; house and stable owners swept their dirt and threw their rubbish into the streets or rivers; and interpersonal violence and fires were all part of life in a town no matter what social position one held (Keene 1982; Dyer 1989; Holt and Rosser 1990). In the 12th century, inadequate surface drainage became a problem as it created rubbish-filled bogs (Keene 1982). Edward III described York in 1332 as the foulest smelling and dirtiest city in England and ordered it cleaned (Miller 1961; Keene 1982).

Air pollution and endemic disease was an ever increasing problem. The air was much polluted through the burning of wood and lime (Roberts and Cox 2003). By the 13th century, coal was beginning to be widely used as a cheap source of fuel as wood became scarce. The pollution from coal in the 13th century was already becoming a problem. The earliest record of air pollution is from 1257, when King Henry III's consort, Eleanor of Provence, was said to have quit Nottingham in 1257 due to the coal smoke adversely affecting her health (Brimblecombe 1975, 1982; Schofield and Vince 1994). Similarly, the stench from the Fleet River in London was so bad in 1290 that a prior from Whitefriars blamed it for the deaths of many brethren (Brimblecombe 1982). Other daily pollutants came from tin, lead, copper, iron, pewter, and mercury (Roberts and Cox 2003). Epidemic diseases, such as leprosy, tuberculosis and treponemal diseases thrived in urban centres; intestinal parasites were more common; and there was higher child mortality in urban centres than their rural counterpart (Dyer 1989; Schofield and Vince 1994).

The diet of those in towns was more varied than among their rural counterparts as there was more choice in what foods were available to them. With improvements in food storage, preparation and trade, there was almost an end to seasonality of foodstuffs. The urban diet consisted of wheat bread, ale, meat and a wider variety and quantity of fruits, vegetables, and fish. Although their diet would not have been dissimilar to the poorer man's, the more wealthy could afford a greater variety and better quality of foods, especially poultry, fish and meats (Dryer 1989; Schofield and Vince 1994). The average house size for the poor was one room in a house or terrace. The labourer faired better with a two-storey house that measured on average 17 x 11.5 feet at ground level, while the craftsman usually had three stories with living quarters and a workshop. The merchant usually enjoyed a stone built home of a double range with a shop at front and basement for storage. Age-at-death in urban centres differed depending on the city and social position of the individual (Platt 1978; Dyer 1989).

3.2.3 Late Medieval England (1300-1550)

3.2.3.1 General Background

The population doubled during the first half of this period (Roberts and Cox 2003). This dramatic increase in numbers and the rising demand for property put strain on the population and economy. With England under such strain and the coming of the Great Famine from 1315-22, the arrival of the Black Death in 1348-50, and the beginning of the Hundred Year War with France, the economic structure of the country broke down.

The bad harvests in 1314 and subsequent years left little food to spare for the under-privileged and the animals. The Crown demanded higher taxes and only bought goods at low prices due to the war with France. All levels of society were affected, although those at the lowest socioeconomic levels suffered the most. Servants and labourers were the hardest hit as many were dismissed from employment. Food prices soared and the demand for wares from trade and craftsmen diminished. Many of the poorer landholders were forced to sell their land to more wealthy peasants (Dyer 2003). It is estimated that the Famine and the Black Death reduced the population by up to 35-50% (Roberts and Cox 2003), or 2.5-3 million people, with no real population recovery and growth occurring until 1520 (Dyer 1989).

Although the plagues and famine years were hard, it was also the salvation of those who survived in the following years. With the population much reduced and the scarcity of available labour, wage earners were able to demand higher pay and better working conditions. There were also more employment and advancement opportunities opened as all sectors of the economy needed both unskilled and skilled workers. This meant that there were fewer people in poverty. Women also benefited as there was more work open to them, although their occupations were still less skilled work than those of men. Food and rents were more affordable. Despite this, families remained small in the 15th century with an average of two surviving children (Dyer 2003).

3.2.3.2 Rural Life

In rural areas the population was reduced by 40-70% with many villages abandoned by famines, the plague, and urban migration (Dyer 2003). By the 13th and 14th centuries the peasant class deteriorated and land-holdings decreased. The core social structure of rural life, the family, began to weaken as land was now not mainly passed to sons but sold to wealthier peasants and the aristocracy, who began to buy up as much land as possible (Dyer 2003). Unlike the period before the plague, land was now readily available and at lower prices (Postan 1972). Many landlords shifted from agriculture as a basis for their income to leasing land and investing in commercial and manufacturing enterprises. With the accumulation of land into larger holdings, agriculture shifted to larger farmsteads, which could produce on a large scale. This being said, many peasants were pushed off the land due to the inability to compete and cope with higher rents, leaving many villages deserted throughout the country. The size of family also decreased from five to two children. Serfdom collapsed as peasants became more mobile and moved to towns or to other areas of the country for paid work (Dyer 1989, 2003). For those who stayed in the country, diets improved with an increased consumption of wheat, ale and meat. Housing also improved during this time as there was a shift from longhouses shared with animals to houses with separate barns and out-buildings. New houses and extensions meant more rooms and, in many cases, a second storey (Dyer 1989). By the 15th century, many houses had glass and lead windows (Wrathmell 1989). The main fuel used was peat and wood, with some reliance on coal (Dyer 1989).

3.2.3.3 Urban Life

The famines and the plagues in the early 14th century hit the urban centres hard due to their high population density. Towns saw a stark reduction in the population, which did not recover until after the Reformation. For instance, York lost almost half of its population between 1377 and 1525. Trade and manufacturing/craft production fell sharply due to the lack of demand. Many private and public properties were in decay and ruin as they were abandoned or left to waste (Dyer 2003).

By the end of the Medieval period the urban environment and economy recovered as the towns began to attract the rural poor for the opportunity of work and more plentiful food. Crafts and trades became more specialized (Dyer 1989). Stronger social networks were formed within the guilds, with elite merchants and nobles at the centre of this network. Many of these guilds worked to improve their surroundings by cleaning up the towns and by keeping civic order (Dyer 2003). The lack of population density seen in previous years combined with abandoned properties increased living spaces and gardens sizes. Local governments and guilds began regular rubbish collections and street cleaning. The water supply was now regularly piped in the town and improvements were made on drainage and public latrines. Backyard rubbish pits were better prepared, lined with stone or brick and were regularly emptied, and wells were lined with wood (Addyman 1989).

Although there were some improvements, the urban living environment may not have completely changed for the better. For instance, it is estimated that in 1520 about one third of the population of London was exempt from taxes due to poverty (Hill 1969). Further, despite measures were taken to clean up the urban environment, urban centres remained unclean living environments. Air pollution began to be an increasing problem as coal was increasingly relied upon and the want for better and safer stone and brick building materials increased the burning of lime (Brimblecombe 1975). The best description of the living conditions in English towns in the late Middle Ages comes from Erasmus (1466-1536):

> “I am frequently astonished and grieved to think how it is that England has been now for so many years troubled by a continual pestilence, especially by a deadly sweat, which appears in a great measure to be peculiar to your country. I have read how a city was once delivered from a plague by a change in the houses, made at the suggestion of a philosopher. I am inclined to think that this, also, must be the deliverance for England.

> First of all, Englishmen never consider the aspect of their doors or windows; next, their chambers are built in such a way as to admit of no ventilation. Then a great part of the walls of the house is occupied with glass casements, which admit light but exclude the air, and yet they let in the draught through holes and corners, which is often pestilential and stagnates there. The doors are, in general, laid with white clay, and are covered with rushes, occasionally renewed, but so imperfectly that the bottom layer is left undisturbed, sometimes for twenty years, harbouring expectorations, vomitings, the leakage of dogs and men, ale droppings, scraps of fish, and other abominations not fit to be mentioned. Whenever the weather changes a vapour is exhaled, which I consider very detrimental to health. I may add that England is not only everywhere surrounded by sea, but is, in many places, swampy and marshy, intersected by salt rivers, to say nothing of salt provisions, in which the common people take so much delight I am confident the island would be much more salubrious if the use of rushes were abandoned, and if the rooms were built in such a way as to be exposed to the sky on two or three sides, and all the windows so built as to be opened or closed at once, and so completely closed as not to admit the foul air through chinks; for as it is beneficial to health to admit the air, so it is equally beneficial at times to exclude it. The common people laugh at you if you complain of a cloudy or foggy day. Thirty years ago, if ever I entered a room which had not been occupied for some months, I was sure to take a fever. More moderation in diet, and especially in the use of salt meats, might be of service: more particularly were public officers appointed to see the streets cleaned from mud and filth, and the suburbs kept in better order…" (quoted in Cheyney 1908: 316-7).

3.2.4 Post-Medieval England (1550-1900)

3.2.4.1 General Background

The Reformation ushered in a transformation not only in religious beliefs and structure, but also saw a change in social frameworks, population growth, technological advancements, and a rise in agricultural production and an industrial revolution. The Dissolution of the monasteries in 1536 broke up monastic lands, much of which was handed to the friends of the Crown. The gentry were now in control of land that was once the Church's, lowering the social position of the clergy and ecclesiastics. The ordinary person was not strongly affected by the Reformation. They still went to church and work as normal. However, a national education system was introduced for all levels of the population. Schools were not just for the higher status or for those of the cloth, they now had a mixture of students from all social strata (although this was not a universal educational system) (Hill 1969).

The population of England boomed during the post-Medieval period. Population growth was not only due to a rise in birth rates, but it also because of a rise in the standard of living, longer life spans, increased food production, stabilisation of food prices, fresh meat available all year round, new hygiene awareness, smallpox inoculations from 1760, dispensaries for the poor, easier to clean cotton clothing, cheaper soap, and a fall in the number of people given the death penalty. Housing had also improved. Houses of cruck and timber construction with thatched roofs were replaced by stone walls and tiles by the 17th century. In 1807 streets became safer at night when gas street lighting was introduced (Hill 1969; Crossley 1990; Outhwaite 1991; Prest 1998; Briggs 2000). At the start of this period, the population was approximately three million. England's population peaked at 5.3 million in the 1650s and stayed at the same level until it boomed at the turn of the 18th century with 5.3 to 5.5 million people, growing to almost 9 million in England and Wales by the end of the 19th century. By 1831 there were over 13.9 million people in England and Wales and by 1851 the total population of the UK was an impressive 27.4 million. The first half of the 19th century the population is estimated to have grown by 73% (Hill 1969; McCord 1991; Outhwaite 1991; Prest 1998).

Along with the population, industry boomed during the Industrial Revolution from the 17th to 19th centuries. One of the most important changes in industry came in 1709 when in Coalbrookdale, Shropshire, coke was used for iron smelting, thus making production cheaper and quicker. The new method did not spread rapidly around the country, but took around 40 to 50 years. By 1750 cast-iron was produced so cheaply that wood machinery was a thing of the past, thus transforming not only industry but also agriculture. Between 1788 and 1806 iron output increased four fold. At the turn of 19th century, one fifth of engines in England were powered by steam. By 1770, 36% of the economy was based on trade and industry, but even by 1831 one third of the work force was still in agriculture, with one in ten in manufacturing. Wool was the largest industry and traded commodity in England in the 17th century until the boom in the cotton industry in 1700-1790. By the end of the 17th century, individuals within the industrial sector became full-time workers, instead of using the industrial job as a supplement to agriculture. This was the beginning of specialisation in industrial occupations. In the early 1830s it is estimated that 450,000 workers were in the cotton industry, 350,000 in the building industry, and less than 100,000 in coal industry. The Industrial Revolution reached its height in the 1830s-1850s, as 93% of exports were manufactured goods, of which 2/3 were textiles (Hill 1969; McCord 1991; Prest 1998).

Industry was boosted by the increase in consumerism and improvements made in transportation. The Industrial Revolution was heavily dependent on the increased consumerism of all social classes. Real wages began to rise for many skilled workers and, with the low food prices of 1730s and 1740s, there was more available money to spend on an ever-increasing number of consumer goods. With the first Improvement Act in 1663 England’s transportation system began to be improved. Early in the 18th century roads began to be regularly maintained and many new roads were built. Coach services and transportation of goods began to be regular, faster, and reached more areas of the country. The canal system was also improved and lengthened, which ensured cheaper transportation of goods, especially that of coal. The introduction of the steam railway system in the 18th century was advanced further in between 1830-1850, with

6802 miles laid. By 1871 the railways doubled in size and passenger numbers quadrupled (Hill 1969; McCord 1991; Prest 1998).

Social divisions during the post-Medieval period went though dramatic changes. The divisions between the rich and poor become wider. Attempts were made to create a static social system. The Act of 1563 Statute of Artificers ensured that only people from well-to-do families could take up a skilled trade; all other individuals had to take up either the occupation of their parent or a lesser position. Further, to leave an employer, the worker needed to have permission or had to buy their way out. If granted leave they were not able move to a better, higher paying job (Hill 1969). Social division during the early 17th century consisted mainly on three hierarchies: high, middle and low/poor classes. An individual's status was not static and changed with their situation, but it was mainly based on their family's position, education, occupation, skill level, self-presentation, property, income, age, sex, birth order, and marital status (Hill 1969; Prest 1998).

After the Civil War between 1642 and 1651, there was a redistribution of wealth, greater social mobility, and freer industry. There was a redistribution of wealth through taxation, which raised some wages, but also throwing more into poverty as many could not afford the new taxes. As the rich merchants gained more wealth, land and influence, their status became almost equal to that of the landed aristocratic class (Hill 1969; Prest 1998). During the 18th century, there were approximately 1,046 individuals with peerages, 1089 individuals with titles but no peerage, 1,000 esquires, and 16,000 gentlemen of a total population of 8 to 9 million (Prest 1998). Below these wealthy merchants and gentry came middle-class merchants, rich artisans, independent peasants, and well-to-do farmers. At the bottom of society were labourers, servants, and those subject to the Poor Laws. By the late 17th and early 18th centuries two new social groups emerge, the industrial master and the worker. Throughout this period, there were striking physical distinctions between the classes. The higher classes tended to be better fed, wealthier, taller and heavier. The poor were also more likely to be conscripted into military service, while the tax-payer was not (Hill 1969; Prest 1998).

Although there was some social mobility, this was mainly reserved to the middle to upper classes. The widening gap between rich and poor became even greater. The old way of sustaining a living from what one could grow themselves to the reliance almost solely on wage-earning occupations helped to create a widening gap between the haves and have-nots. Also, social attitudes of the population began to change; especially that of the middle class, which viewed the poorer classes with apathy, as beneath them, as being unclean and uncivil. This negative opinion towards the poor not only alienated them, but also kept them in their situations as no adequate help or relief was available to them. Further, the labouring classes began to suffer as their worth decreased as the population and work force increased. New Wage Laws and Poor Laws were introduced to deal with the increasing problem. From 1580s-1590s and again in the 1620s and 1650s, there were depressions caused by inflation, declining wages, a part-time labour force, and bad harvests. Riots become a normal occurrence throughout the country. There were also many additional social control laws. The 1662 Act of Settlement allowed any parish to reject a newcomer who could not support themselves and to return them to their legal residence. This immobilised the labourers and kept labour cheap. There was some reprieve in 1697 when labourers were allowed to apply for a certificate to be allowed to resettle in a different area of the county, but they were hard to obtain

(Hill 1969; Prest 1998). The 18th-century political economist Joseph Massie estimated that 81% of his study population had an annual family income of less than £50, with a minimum £40-50 required to be considered middle class. The average skilled worker made £60 a year; while the unskilled worker took home only £15 12s (Prest 1998).

Diets were generally improved during the post-Medieval period. Sugar imports became widely and cheaply available to all levels of society, enabling them to vary their diets. Rice was introduced in the middle of the 18th century and potato crops increased. Tea was also widely available and affordable and it began to replace alcohol as the regular beverage of choice. Although there were some improvements, from 1615 to 1700 tobacco use also increased and spirit consumption trebled from 1710 to 1751. The working class and poor also suffered malnutrition. It is estimated that the average working poor had a daily calorie intake of 2500-2700, which is much lower than the 3500-4000 calorie intake of those who are involved in similar physical activity today. A skilled worker would consume little meat and, in the North, the worker lived mainly on potatoes and black bread. Many parents sent their children into work as all they had to feed them was bread and water. Children usually went to work in the factory at the age of seven and laboured 12-15 hours six days a week, until the Factory Acts of 1833 reduced their hours to no more than 48 hours a week for 9 to 12 year olds and 69 hours a week for 13 to 18 year olds. Child mortality rates were at least 20 times higher than today, as one in four died before the age of 10 years. At the beginning of the 18th century it is estimated that one in every five persons was receiving poor relief. However, by the early Victorian period things had improved with only one in ten people on poor relief during the bad years and one in 15 during the good (Hill 1969; McCord 1991; Prest 1998).

The climate during the post-Medieval period improved, but there were still years of dearth. The mid 16th century saw a 'little ice age' with colder temperatures than there is today, bringing many years of dearth and a high mortality rate (Brimblecombe 1982). The climate began to warm from 1550-1700, ending years of high number of bad harvests. After this period, bad harvests were less frequent and not as severe, and the poor were able to survive them. During the post-Medieval period there were many years when food production did not keep up with the population's expansion. This brought nutritional deficiencies, a rise in infectious diseases and social disturbances. Food and grain riots became a common occurrence across the country in both rural and urban settings. Those who lived in towns were better-off during the dearth years because of the increased availability of food, higher wages, and better poor relief (Hill 1969; Outhwaite 1991).

As with the previous periods, improvements in living conditions were largely inadequate. Not only were rises in the average income unequal, so were the improvements made to housing, health dispensaries, and sanitary conditions. There were many government acts that moved to clean up the towns and villages. Between 1785 and 1800 there were as many as 211 Improvement Acts passed, including mention of paving, lighting, water supply, rubbish removal, and providing policing (Briggs 2000). Most of these were ineffectual and short-lived. Even by the time of the publication of Edwin Chadwick's eye-opening report into the lives of the working class in 1842, the situation had changed very little. He concluded the report with a disturbing picture:

> '…the various forms of epidemic, endemic, and other disease caused, or aggravated, or propagated chiefly amongst the labouring classes by atmospheric impurities produced by decomposing animal and vegetable substances, by damp and filth, and close and overcrowded dwellings

> prevail amongst the population in every part of the kingdom, whether dwelling in separate houses, in rural villages, in small towns, [or] in the larger towns….the annual loss of life from filth and bad ventilation are greater than the loss from death or wounds in any wars in which the country has been engaged in modern times' (Chadwick 1965: 422).

3.2.4.2 Rural Life

During the majority of the post-Medieval period, most of the English population was employed in agriculture and lived in rural villages of about 700 people. In 1688 it is estimated that 88% of the population was engaged in agriculture. By 1700 over 40% of the economy was still based in agriculture and accounted for about three-fifths of the male labour force. However, by the mid 19th century, only one-third of the population was employed in agricultural occupations (Hill 1969; McCord 1991; Prest 1998).

The rural setting changed after the Reformation and with the introduction of the Enclosure Acts of 1606, 1621 and 1624. Church lands were also released and sold during the Reformation. Further, in 1646 feudal tenures were abolished. This period saw cultivation of common lands, forests, wetlands, and wastelands. Advances in farming techniques and equipment more than doubled the productivity of arable land in the 17th century from its 15th-century levels. Lands were bought up and estates were joined to form, larger, commercial farms. Those individuals who could, bought as much land as possible, which raised many from peasant to gentleman status. Those who could not afford to buy land suffered through high rents and taxation. In 1643 a land and excise tax was introduced, forcing many more people off their lands. Peasants started to be evicted or bought out by the larger farmers or mining operations. Changes in the rural environment forced many to be dependent on wages and charity. By 1790 the higher classes owned almost one-fourth of the total cultivated land and by 1830 farm labours were only making an average of one-eighth the salary of a skilled worker (Hill 1969;

Crossley 1990; McCord 1991; Prest 1998; Briggs 2000).

Rural areas began to suffer not only from the redistribution of land but also through changes in market strategies. Even with the commercialization of agriculture the population increased more quickly than the farms could produce, and there were still many years of bad harvests and dearth. There were at least 124 anti-enclosure riots between 1603 and 1625 and hundreds of food riots in the 18th century. A change in how grain was distributed might have been a reason for the increase in rioting in the 17th century and 18th century. During this period farmers began selling all their grain to middlemen who, in turn, sold in bulk only to retailers. The average household now had to buy their flour from the retailer in bulk and not directly from the farmer as they had done before. Further, the grain moved to where there was the most demand (i.e. to the towns), and did not necessarily feed the people of the farming community that produced it (Hill 1969; Prest 1998).

There were some improvements in rural life, but on the whole the post-Medieval period saw a decrease in living conditions. Improvements in transportation and the new consumerism trend helped to bring many villages out of isolation. Increased consumer demands brought the opening of village general stores in the 17th century. By the 18th century, a wider variety of goods and stores were available to the rural market (Hill 1969). However, by the middle of the 19th century many individuals in rural England were living in poor conditions, subject to low wages with no alternative employment possibilities, paid high taxes, had inadequate poor relief and many experienced long periods of unemployment. A comparison with some of the worst slums in towns saw the poor of the rural village worse off. Agricultural labourers were living in overcrowded damp houses with no flooring, with open gutters and cesspools located near the house. The people were often found to be badly fed, badly clothed, dirty, and living on a diet of bread and potatoes with little meat. Those that were paid enough lived in better cottages, which were less crowded and cleaner (Chadwick 1965; McCord 1991).

3.2.4.3 Urban Life

By the 16th century there were 800 market towns in England and Wales. The urban population boomed during the post-Medieval period. During the 1520s only 5.5% of the population lived in towns with a population over 5000 people. This soon changed, as 13.5% of the population lived in towns in 1670 and by 1801 the proportion was 27.5%. The population increase was more dramatic in industrial towns. However, it was not until 1851 that the majority of the population lived in towns. In the late 17th and early 18th centuries there were 67 urban centres with a population of 2500, of which 30 had 5000 or more individuals. In London, the population nearly quadrupled by 1600 to 200,000 people. By 1700 the capital city had half a million people or one in every 10-11 people living in England; and between 1801 and 1831 its population almost doubled. London became the centre of the country. London’s demand for domestic imports helped the prosperity of the rest of the nation and stimulated industry. It started fashions, consumer tends and lifestyle changes that quickly spread to the rest of the nation. By 1850 one-fourth of the population lived in urban centres of over 5000 people. In 1861 more people lived in an urban setting than the rural by five to four and by 1881 two-thirds of the population was urban (Hill 1969; McCord 1991; Outhwaite 1991; Prest 1998).

Population levels in the city were often checked by epidemics and high mortality rates.

For instance, the 1635 plague had killed almost half of Newcastle's population. In London only one in ten individuals survived to reach five years of age, with a life expectancy at birth of 17.5 years. In the years 1750-69 there was a 63% mortality rate for children under five years in London. Those in the workhouses only had a 7% chance of surviving between 1763 and 1765. In 18th-century Nottingham one in every two children baptized died, and the death rate in a Lancashire town was twice that of a rural village. High mortality rates were not only seen in the lower classes. Well-off families were estimated to lose two of every five children born to them in the 16th century. Although the average life expectancy had risen to 39.9 years for men and to 41.9 years for women during the first part of the Victorian period, the average was much lower for those poor living in industrial cities and could be as low as 15 years. In the poorer areas of England it is estimated that in the 1840s at least one half of the children died before five years of age (Hill 1969; McCord 1991; Outhwaite 1991; Prest 1998).

Two of the biggest dangers of life in the city during the 17th to 19th century were pollution and poor sanitary conditions. Throughout this period there were many government acts that were intended to improve conditions in the urban environment, but these were half-hearted and short-lived. Even when Chadwick published his damming report on sanitary conditions of the working class, the government did not make it their main concern. Environmental conditions in the city are reflected in the literature and art of the 17th to 19th century. Many portray despair and depression, and often describe the cities as smoky and soot-laden, and having poor weather, acid rain, and blackened buildings. Pollution increased as the reliance on coal became even stronger due to the dramatic increase in the price of wood. In London this increase was as much as 780% between 1540 and 1640, making wood too expensive to use for an everyday fuel.

Although a great advancement, the invention of the steam engine for industrial use insured that the pollution levels of urban centres worsened. On the domestic level, coal burning was not controlled until the 20th century, and it was not until 1814 that there was any legislation concerning air pollution, and these were ineffective. There are many documents that indicate that travellers to London and other British cities found them to be full of the smoke and fog from the 17th century. In 1897 Mossman's meteorology records of London indicate that there was a marked increase in fogs from 1720 to 1890. The industrial towns of the North and of the Black Country were famous for their poor environmental conditions and even those from London commented on the poor quality of air and living conditions of the North (Brimblecombe 1978, 1982; Matossian 1985; Briggs 2000).

By the end of the 17th century there was better housing and privacy in towns for all but the poorest class. In 1760 many towns also set up improvement commissions to clean up the urban environment, and many towns had regular doctors. The well-off did see a decrease in the population density per house, but the worker saw an increase. In Liverpool the average number of persons per house was 6.9. A total of 655 individuals lived in only 27 houses—with an average of five rooms—in a poor district of London in 1841 and by 1847 this increased to 1095 individuals, with an average of 8.1 persons per room. In many of the poor areas of the city there were open drains and sewers that produced noxious gasses and unpleasant smells; the ground was often marshy with stagnant pools of water; and rubbish piles were common. Houses were built back-to-back without flooring on unpaved narrow streets, many with no widows, no connecting drains, and with poor or no water supply. Even in Windsor where most of the population was wealthy, there were open ditches and sewers giving off a bad stench.

The water supply was poor and the drainage system was ineffective (Chadwick 1965). The working class and the poor areas of the city were the worst off. Chadwick (1965: 219) found that "on inquiry into the sanitary conditions of the population in different districts, that average chances of life of the people of one class in one street will be 15 years, and of another class in a street immediately adjacent, 60 years."

3.3 The Samples

The material for this research is comprised of 1753 skeletons (of varying completeness) from 11 skeletal populations—from Blackfriars, Gloucester; Chelsea, Middlesex; Chichester, West Sussex; Fishergate, York, North Yorkshire; Hereford, Herefordshire; Hickleton, South Yorkshire; St. Helen-on-the-Walls, York, North Yorkshire; Towton, North Yorkshire; Wharram Percy, East Riding of Yorkshire; Wolverhampton, Staffordshire; and York Minster, York, North Yorkshire—dating from the late Anglo-Saxon period to 19th century in England (Tables 3.1-3.4, Figure 3.1). There are 409 subadults and 1344 adults, of which, 812 are male and 519 are female (with 13 of indeterminate sex). Individuals are from a wide range of age groups, sex, health status, and social status.

Figure 3.1: Map of sample populations.

Table 3.1: Populations used in this study.

Site	Referred to in text as	N	Period	Socio-economic context
Blackfriars, Gloucester, Gloucestershire	Blackfriars	55	AD 1239-1539	Urban, middle to low status
Chelsea Old Church (Formerly St. Luke's and All Saints), Chelsea, Middlesex	Chelsea	52	AD 1695-1842	Rural, high status (?)
Hospital of SS. James and Mary Magdalene, Chichester, West Sussex	Chichester	277	ca. AD 1118-1689	Hospital
St. Andrew's, Fishergate, York, North Yorkshire	Fishergate	301	ca. AD 900-1538	Urban, middle to high status (?)
Cathedral Church of St. Mary and St. Ethelbert, Herefordshire	Hereford	223	ca. AD 680-1550	Urban, high to low status (?)
St. Wilfrid's, Hickleton, South Yorkshire	Hickleton	25	c. AD 1150-ca. 1850	Rural, agricultural settlement
St. Helen-on-the-Walls, Aldwark, York, North Yorkshire	St Helens	243	ca. AD 1100-1550	Urban, low status
Battle of Towton Mass Grave, Towton, North Yorkshire	Towton	31	AD 1461	Combatants
St. Martin's, Wharram Percy, North Yorkshire (Formerly East Riding of Yorkshire)	Wharram Percy	275	ca. AD 950-1850	Rural, agricultural settlement
St. Peter's Collegiate, Wolverhampton, Staffordshire, West Midlands	Wolverhampton	84	AD 1819-ca. 1870	Urban, low status
The Cathedral and Metropolitical Church of St. Peter, York, North Yorkshire	York Minster	187	ca. AD 600-1800	Urban, high status

Table 3.2: Summary of population demography of included individuals.

		N			Sex			Age								
Site	Period	Total	Adult	Juv	M	F	I	F-IN	EC	LC	AD	Adult	YA	YMA	OMA	MA
Blackfriars	Medieval	55	39	16	21	17	1	1	6	6	3	1	4	8	4	21
Chelsea	Post-Medieval	52	48	4	25	23	0	3	1	0	0	2	6	4	6	30
Chichester	Medieval	277	223	54	144	75	4	3	21	16	14	11	23	61	54	74
Fishergate	All	301	250	51	181	67	2	2	20	15	14	16	27	63	79	65
	Anglo-Saxon	48	38	10	19	18	1	1	4	3	2	1	6	10	11	10
	Medieval	233	200	33	156	43	1	1	11	10	11	12	19	48	67	54
	Not Phased	20	12	8	6	6	0	0	5	2	1	3	2	5	1	1
Hereford	All	223	168	55	80	87	1	1	15	19	20	3	23	60	37	45
	Anglo-Saxon	16	10	6	7	3	0	0	3	2	1	0	1	3	2	4
	Medieval	207	158	49	73	84	1	1	12	17	19	3	22	57	35	41
Hickleton	All	25	16	9	9	7	0	5	2	2	0	0	3	7	4	2
	Medieval	8	5	3	3	2	0	0	2	1	0	0	1	1	3	0
	Post-Medieval	17	11	6	6	5	0	5	0	1	0	0	2	6	1	2
St Helen’s	Medieval	243	182	61	106	76	0	3	17	29	12	10	9	52	54	57
Towton	Medieval	31	31	0	31	0	0	0	0	0	0	1	9	10	8	3
Wharram Percy	All	275	169	106	83	86	0	17	36	35	18	0	22	42	36	69
	Anglo-Saxon	9	9	0	3	6	0	0	0	0	0	0	1	4	0	4
	Medieval	34	32	2	16	16	0	0	0	2	0	0	5	8	10	9
	Post-Medieval	40	31	9	17	14	0	2	1	2	4	0	3	6	7	15
	Not Phased	192	97	95	47	50	0	15	35	31	14	0	13	24	19	41
Wolverhampton	Post-Medieval	84	60	24	31	29	0	10	7	3	4	6	4	12	22	16
York Minster	All	187	158	29	101	52	5	1	11	7	10	45	12	45	39	17
	Anglo-Saxon	82	79	3	49	28	2	1	2	0	0	28	3	17	23	8
	Medieval	90	68	22	48	17	3	0	7	6	9	12	9	24	14	9
	Post-Medieval	8	4	4	1	3	0	0	2	1	1	2	0	1	1	0
	Not Phased	7	7	0	3	4	0	0	0	0	0	3	0	3	1	0
Total	All	1753	1344	409	812	519	13	46	136	132	95	95	142	364	343	399
	Anglo-Saxon	155	136	19	78	55	3	2	9	5	3	29	11	34	36	26
	Medieval	1178	938	240	598	330	10	9	76	87	68	50	101	269	249	268
	Post-Medieval	201	154	47	80	74	0	20	11	7	9	10	15	29	37	63
	Not Phased	219	116	103	56	60	0	15	40	33	15	6	15	32	21	42

Juv=Juvenile, M=Male, F=Female, I=Indeterminate, F-I=Foetal-Infant, EC=Early Child, LC-Late Child, AD=Adolescence, YA=Young Adult, YMA=Young Middle Adult, OMA=Old Middle Adult, MA=Mature Adult,

Table 3.3: Reported demographic and pathological analysis of included populations.

	N		Age				Stature		Dental Pathology		
Site	Adult	Subadult	Juvenile	Adults over 45	Adults Over 35	Subadults Under 5-6 years	Male Mean	Female Mean	Caries	Enamel Hypoplasia	Source
Blackfriars	78	51	39.5%	33.3%	46%	43%	169.2	155.7	24.8%	20%	Wiggins *et al*. (1993)
Chelsea	168	33	19.6%	36.4%	59.6%	11.1%	168.4	163.4	42.5%	41.3%	Bekvalac and Kausmally (2005,2007)
Chichester	280	104	27%	25.8%	49% (>30)	64.5%	169.7	159.4	72%	80.3%	Lee (2001), Magilton *et al.* (2008)
Fishergate	312	56	22.4%	45.1%	73.5%	21.2%	171.2	158.9	52%	53.9%	Stroud and Kemp (1993)
Hereford*	884	310	26%	25.3%	43%	31.3%	170.3	159.3	----	----	
Hickleton	52	19	36.5%	13%	26%	22%	170.4	160.3	65%	50%	Stroud (n.d.)
St Helen's	724	317	30.5%	23%	54.10%	63%	169.3	157.4	38%-41%	40.8%	Dawes and Magilton (1980)
Towton	38	0	0%	10.5%	33%	0%	171.6	----	85.7%	32.1%	Fiorato *et al.* (2000)
Wharram Percy	687	327	47.6%	33.1%	65.3%(>30)	63.3%	168.8	157.8	68%	30.2%	Mays (2007)
Wolverhampton	92	58	38.7%	15.3%	32.6%	76%	171	160.6	69.2%	58.4%	Arabaolaza *et al* (2007)
York Minster	311	56	15.3%	26.5%	58%	35.4%	171.8	159.5	50.5%	----	Dawes (n.d.)
Anglo-Saxon	214	21	9%	40%	81%	33.3%	173	161	34%	21 (32.8%)	Lee (1995, n.d.), Dawes (n.d.)
Medieval	93	34	27%	13%	35%	47%	170.6	157.9	21%	----	Dawes (n.d.)

*The Hereford information is incomplete as the skeletal collection is in the finishing phases of its publication. Special thanks to A. Boylston and D. Weston for the early release of this data.

Table 3.3: Continued.

	Infectious disease				Metabolic Disease			Other				
Site	Maxillary Sinusitis	Periostitis (Tibiae)	Rib Lesions	TB	Rickets	Cribra Orbitalia	Scurvy	DISH	Malignant Neoplasm	Fractures	Other	Source
Blackfriars	----	19.6-22.3%	1	0	1	7.8%	----	6	1	9%	1 treponemal, 1 leprosy	Wiggins *et al*. (1993)
Chelsea	3	----	----	3	17	8.6-9.1%	2	11	----	14.6%		Bekvalac and Kausmally (2007, 2005)
Chichester	58.3%	43%-adults 8%-subadult	21	22	5	56%-adults 29%-subadult	5	12	5	34.8%	75+ leprosy, 3 treponemal	Lee (2001), Magilton *et al.* (2008), Roberts (2007)
Fishergate	----	----	----	----	----	42.8%	----	7	2	19.1%	----	Stroud and Kemp (1993)
Hereford*	----	----	11	10	----	----	----	----	----	----	----	Boylston *et al.* (2007)
Hickleton	1	8%	3	1	2	----	0	----	0	----	----	Stroud (n.d.)
St Helen's	71.9%	----	----	----	----	----	----	----	----	5%	----	Dawes and Magilton (1980), Roberts (2007)
Towton	3	6.7%	18	0	0	32.1%	0	0	0	99-100%	----	Fiorato *et al.* (2000)
Wharram Percy	50.9%	21	8	9	8	25%	0	5	1	10.6%	----	Mays (2007), Roberts (2007)
Wolverhampton	3	15.6%	16.2%	1	5	10.5%	1	1	3	14.6%	2 possible treponemal, 3 amputations	Arabaolaza *et al* (2007)
Anglo-Saxon York Minster	6.7%	----	----	----	----	6	----	----	----	6	----	Lee (1995, n.d.), Dawes (n.d.)

*The Hereford information is incomplete as the skeletal collection is in the finishing phases of its publication. Special thanks to A. Boylston and D. Weston for the early release of this data.

3.3.1 York, North Yorkshire

3.3.1.1 Historical Evidence

Three of the sample populations included in this study come from within the city of York, North Yorkshire (Figure 3.2). As they share similar historical backgrounds, this section will give a general history of York and the following three sections will give a more specific discussion of events directly related to each site. These samples are York Minster (Section 3.3.2), St. Andrew's, Fishergate (Section 3.3.3), and St. Helen-on-the-Walls, Aldwark (Section 3.3.4).

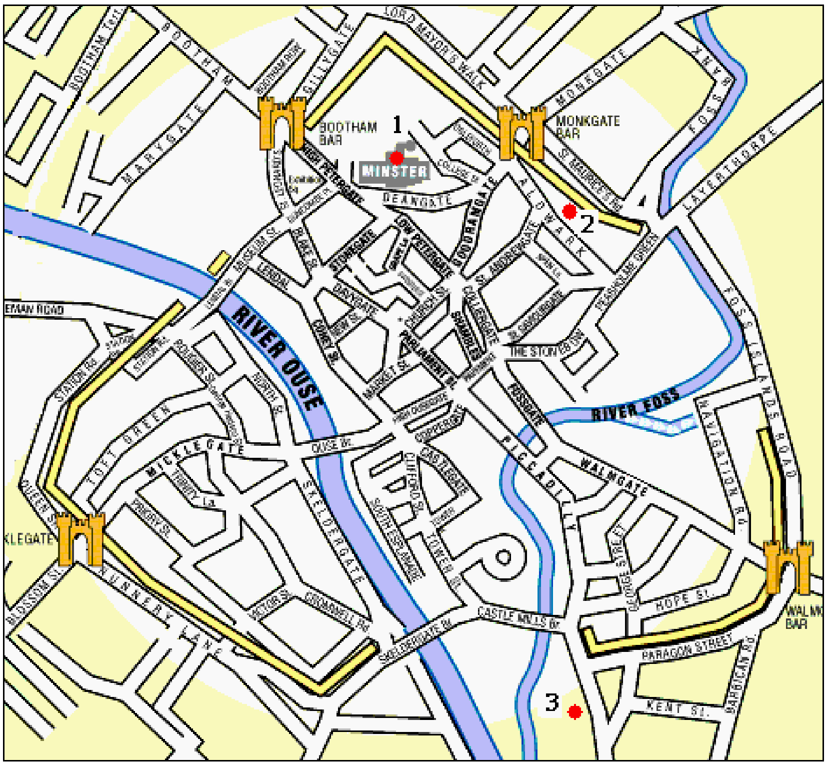

Figure 3.2: Map of sites in York.
1) York Minster 2) St. Helen-on-the-Walls, Aldwark
3) St. Andrew's, Fishergate.

Although it had undergone a decline with the withdrawal of Roman forces, York at the beginning of the Anglo-Saxon period was an important royal centre (Heywood and James 1995; Russo 1998). The first documentary evidence of Anglo-Saxon York are letters written by Pope Gregory the Great in 601, which indicate that the city had become the second metropolitan see in England (Dickens and Ramm 1961; Rollason

1999). York's importance as an urban centre is reflected in the early establishment of a mint in the 7th century (Heywood and James 1995; Russo 1998; Hall 1999; Rollason 1999). By the writing of the Domesday Book, York was the largest settlement outside of London with a population estimated to be 4,000-5,000 people, although contemporaries boasted that the population was of 30,000 adults. At this time, York had around 1800-2000 houses and was divided into seven shires. The main occupations were military, church, law, administration, meat-marketing, coin-minting, carpentry and milling. As discussed in section 3.2, the living conditions within the city were poor during the Anglo-Saxon period, especially due to a population boom and increased building density. (Dickens and Ramm 1961; Miller 1961; Heywood and James 1995; Russo 1998; Hall 1999; Rollason 1999).

By the 9th century York saw an increase in prosperity and influence. The core of the population was a mixture of Anglo-Scandinavian settlers and later Norman invaders and those of a local background. The population continued to grow and the settlement expanded in both the area around the Minster and its suburbs. There were further population increases due to the visitations and residence of the Royal Court and government in the city at varying times throughout the Medieval and post-Medieval period, as York served as the second defence of England against Scotland. The seven years during the Scottish wars of 1298-1337 were the longest period of residence of England's government in the city. York also served as an important ecclesiastical centre. By the end of the Medieval period York had the Minster, four monasteries, seven major hospitals, and 39-44 parish churches (Rollason 1999). Throughout the Medieval period York was considered the social centre of Yorkshire and served as a resort for the wealthy and royal (even in its later decline) (Miller 1961).

Although influential and often the home to Royalty, during the Medieval period York's wealthy residents were few in number, with many residing in the countryside. The majority of the population were tradesmen and craftsmen of modest or poor means. The most profitable markets and trades in the city were food and wool. The next most popular trade was in leather, with 30% of the population employed in the craft, followed by metal crafts representing 17% of the workforce. Apart from the nobles' and wealthy merchants' grand stone dwellings, housing remained mainly of timber and located on crowded, unpleasant streets. The environmental and sanitary conditions continued to be undesirable and in many senses had worsened (see previous discussion). City records, such as wills and claims to property, suggest that there was a high mortality rate (Miller 1961).

The second half of the 14th century witnessed a downward turn in population and the economy of York. In 1349 the Black Death arrived, which was followed by further outbreaks in 1361, 1369, 1375, and 1378. The resulting population decline was furthered by the War of the Roses in the 15th century. Not only did this war involve many of York's residents but the conflicts also physically destroyed many parts of the city. Estimations from poll tax indicate that the population of the city was about 13,000 at the end of the 14th century, but by the end of the 15th century it had fallen to below 8,000. Moreover, in 1377, York was rated second in wealth of all English cities; however, by the 16th century it had fallen behind many other centres. Records indicate that the value of property was found to have fallen between 40 and 66%, with many rented properties noted as being in disrepair (Miller 1961).

The late 15th and 16th centuries saw a few improvements. Derelict properties were combined for larger living spaces. Butchers were restricted to disposing of their rubbish outside the city, every ward had regular rubbish collections, and more springs were opened. Space was also freed in 1536-9 and 1547-53 as all of the monasteries, friaries, chantries and hospitals in York were turned over to the Crown and private hands after the Dissolution of the monasteries, many being demolished (Moulden 1999). In 1482 prostitution was banned and in the early 16th century vagabonds were punished or driven out. Although there was some effort to improve conditions in the city, there were further serious outbreaks of bubonic plague in 1538, with a 30-50% death rate in some parishes. The population remained at about 8,000 until it started to rise again in 1600 to 10,000 (Dickens 1961; Forster 1961).

York in the early 17th century was recovering from economic decline, made worse by famine and epidemics. The population of the city by 1630 recovered to approximately 12,000 people. Nevertheless, the city's recovery was interrupted by the Civil War. During the conflicts, there was a siege of the city in 1644 by parliamentary forces, which saw many of York's buildings damaged or destroyed. Once the Royal garrison had withdrawn from the city in 1688, stability returned and the city recovered. Afterwards, York flourished as a market town, coaching centre, and the centre of professional and social activities in England. Many of the smaller tenements were combined into larger buildings and grand Georgian town houses and public buildings were erected. York still remained the social centre, resort and residence for many gentry in Yorkshire. By 1864 major alterations to the city's layout were made due to industrialisation, road and bridge building, the construction of a railway, and the erection of new housing estates. The population in 1821 grew to 19,000 people, but by the end of the 19th century this had increased to almost 70,000 (Allison and Tillott 1961; Forster 1961; Moulden 1999).

3.3.2 The Cathedral and Metropolitical Church of St Peter (York Minster), York, North Yorkshire (ca. AD 600-1800)

3.3.2.1 Historical Evidence

The first mention of a church on, or near, the site of the present-day York Minster is that of a timber-framed church dedicated to St. Peter the Apostle. St. Peter's was first mentioned in records of King Edwin of Northumbria's baptism in 627 AD. The exact location of the Anglo-Saxon timber-framed church has yet to be discovered, although a likely location is suggested to be to the south of the existing church near what is now the junction of Stonegate and Petergate. It is known to be located over the old Roman legionary headquarters building, which was located at the centre of the old Roman legionary fortress. (Dickens and Ramm 1961; Tillott 1961; Phillips 1985; Carver 1995; Russo 1998; Hall 1999; Rollason 1999). York's importance quickly grew and, in 735, York became an archbishopric and was considered a place of great ecclesiastical importance (Rollason 1999). In addition, during the 7th and 8th centuries the Minster became Northumbria's chief royal and episcopal burial ground (Phillips 1985; Russo 1998, p 122; Rollason 1999). High status burials at the Minster may include a sub-king of King Ecgfrith's, two of King Edwin's children, Eadberht (who reigned in York in 737/8-58), and many of the area's ruling nobles (Rollason 1999; Buckberry 2007).

The Minster was unaffected by the Viking invasion of York in 866, and although the new settlers established their own churches, the new leaders continued to use the Minster's burial ground as indicated by the elaborate Anglo-Scandinavian grave markers. However, in 1069 the Minster was destroyed during the Norman Conquest. A new Minster was not constructed until after 1079 by Thomas De Bayeux. He constructed a grand Minster on top of the old Roman legionary fortress and pre-

Conquest graveyard. The building was further added to by Walter de Gray and John Romeyn in the 13th century. Many other refurbishments and additions were made until the 15th century, after which it has remained unchanged except for repairs (Tillott 1961; Phillips 1985; Hall 1999; Rollason 1999).

3.3.2.2 Archaeological and Osteological Evidence

York Minster was excavated between 1969 and 1973 by the York Minster Excavation Committee (Phillips 1985, 1995a). The remains are now curated at the Minster. More than 300 individuals were recovered along with a large number of disarticulated remains (Dawes n.d.). Due to 30 years of poor storage conditions, many of the complete skeletons have been mixed with the disarticulated material. For the current study, 187 individuals were complete enough to be included in this study (see Table 3.2), although it should be noted that 51 of the individuals had only their crania present (three of which also had mandibles). Of the individuals, 29 were juvenile and 158 were adults, with 101 males, 52 females, and five of indeterminate sex. There are three main areas from which skeletal remains were recovered: the Anglo-Saxon/Scandinavian cemetery, Medieval to post-Medieval intramural burials, and medieval burials from Chapter House yard.

The Anglo-Saxon/Scandinavian cemetery is the most extensively studied and published of the burial areas. There were a total of 235 individuals recovered from this cemetery, of which only 67 have been subject to pathological examination (Lee 1995; Dawes n.d.; Lee n.d.). The cemetery was found in the area of the Roman *principia*, located to the south-west of the Minster under the South Transept. The burials were found to respect the Roman fortress and defined by walls of the *basilica* and the headquarters building (Carver 1995; Phillips 1995a, 1995b). The status of individuals buried in the Anglo-

Saxon/Scandinavian cemetery is unknown. It is possible that the Minster cemetery was employed solely for royal and ecclesiastical burials, but it is likely that these may have been restricted mainly to intramural burials in the church, which have yet to be uncovered. The cemetery may also have been a combination of the local and the incoming Anglo-Saxon/Scandinavian populations. However, there is evidence that many of the individuals were of high status, as evidenced in the elaborately sculpted grave markers, grave slabs, charcoal graves, and grave inclusions (such as gold thread) (Carver 1995; Phillips 1995b; Hadley 2002; Buckberry 2007). In comparison with the other sites examined for the current research, the Anglo-Saxon/Scandinavian group had a low representation of juveniles at only 9% of the sample, of which 33.3% had died before the age of six years. The Anglo-Saxon population from the Minster also had the highest number of individuals over the age of 35 years at 81%, the tallest male mean stature at 173 cm, the second highest female stature of 161 cm (Lee 1995, n.d.), and the lowest prevalence of maxillary sinusitis (see Tables 3.3-4).

The remaining Medieval to post-Medieval burials have not yet been subjected to extensive research and attention. They consist of 127 individuals from intramural burials within the existing Minster, located in the west end of the nave, choir ambulatory, Lady Chapel, transept, crossing, east end of the nave, and from the crypt. This group includes one named individual, Archbishop Greenfield (d. 1315). There were also medieval burials from the Chapter House yard, the total number of which cannot be confirmed because the skeletal material has yet to be assessed or analysed. The original skeletal report (Dawes n.d.) includes all but the burials from the Chapter House yard. However, the report’s focus is on the Anglo-Saxon/Scandinavian group and apart from caries prevalence, there is no pathological analysis of the Medieval to post-Medieval population available for general comparisons.

3.3.3 St Andrews, Fishergate, York, North Yorkshire (ca. AD 900-1538)

3.3.3.1 Historical Evidence

St. Andrew's was located in the Fishergate area and south-west of the Walmgate entrance to the medieval walled City of York, just east of the joining of the Rivers Foss and Ouse and south of the old Roman fortress. The planned settlement of Fishergate was founded in the 8th century as a Frisian commercial and industrial settlement (Hall 1999). There is evidence of early trading activity in the Fishergate area until c. 860 AD and evidence of abandonment of the site by 1000 AD (Addyman 1989; Kemp and Graves 1996; Rollason 1999). The earliest written evidence of a church dedicated to St. Andrew's in the Fishergate area was in the Domesday Book. This Anglo-Saxon church was later replaced by a Gilbertine priory founded by Hugh Murdac in 1192-1202 (Burton 1996). St. Andrew's was founded during the decline of the Gilbertines and was considered to be only a lesser house. The priory was to have 12 resident monks and an abbot, but it is unlikely it ever reached this number. By 1380-1 there were only three canons and the prior in residence, while at the dissolution there were only two canons and a prior (Page 1974; Sullivan 2004). At its beginning, the priory owned four to five tenements in addition to a substantial endowment of rents and property within the walls of York and in the surrounding area. By 1230 they owned 13 houses in York and many in the surrounding areas, although the priory was never considered to be a wealthy institution and was valued on at only £59 (Stroud and Kemp 1993; Burton 1996). The Gilbertine order went into decline in the 14th century in York, with the local population not supporting these houses. This lack of support is suggested by high number of the church patrons who sought burials outside of York (Kemp and Graves 1996). In 1335 the priory was so poor that it could not afford the much needed repairs, relying instead on a grant from the crown. The situation was aggravated in 1360 when the priory's tenants withdrew their rents and services, and it was granted protection under the King. During the last half of the 15th century St. Andrew's was often referred to as being impoverished. In 1535 St. Andrew's retained its 13th-century value, while the other Gilbertine houses in Yorkshire were worth between £170-240. As the priory was worth less than the £200 needed to keep its doors open during the Reformation, the priory was surrendered in 1538 (Stroud and Kemp 1993; Burton 1996).

The demography and wealth of the lay population living in the Fishergate area that was most likely to utilise the burial ground is unknown (Burton 1996; Kemp and Graves 1996). During its existence as an ecclesiastical site, the priory was not often mentioned in wills. Only a few records exist of bequests to the priory and only one will stated that the individual wanted to be buried at the priory (Stroud and Kemp 1993; Burton 1996). Further, these donations and bequests to the priory were small and from people of modest wealth. Due to this loss of interest in the priory from high society, the social rules for intramural burials may have been disregarded in the later stages of the priory's occupation (Sullivan 2004).

3.3.3.2 Archaeological and Osteological Evidence

Excavations of St. Andrew's, Fishergate, were carried out from 1985 to 1986 by the Yorkshire Archaeological Trust (YAT). There were deemed to be two periods in which burials took place at the site, Period 4 dating to the 10th century to the 11th century and Period 6 dating to 1195 to the late 16th century. Four hundred and two individuals were recovered from these two periods (Stroud and Kemp 1993), which are now curated by YAT. Of these individuals, 301 were complete enough to be included in the present research, of which 51 were subadults and 250 were adults (181 males, 67 females, and two indeterminate) (see Table 3.2).

The occupation of Period 4 consisted of a cemetery in the south-western corner of the site possibly in association to a timber church. At this time, the Fishergate settlement was considered to be a suburb of York. The settlement was on one of the major routes in and out of the city, which was perfect for trading. However, the majority of evidence indicates that this settlement had more rural aspects and was not part of the urban centre. One hundred and thirty-one burials of the lay population were uncovered in Period 4. Of these, at least 19 males were found to have died from blade injuries, suggesting they had been killed either at the Battles of Fulford and Stamford Bridge in 1066 or the Battles for York Castle in 1067-9 (Kemp and Graves 1996).

The Period 6 cemetery consisted of 271 burials, which were associated with the Gilbertine priory of St. Andrew. Burials took place in three main areas of the site: the south cemetery, church, and eastern cemetery. Burials within the church usually consisted of those from the higher ranks amongst the monastic community and the upper classes, their families and founders from the lay population. Burials in the south cemetery were mainly that of the local lay population and resident lay workforce, while the east cemetery was solely for the resident community. Although monasteries were known to have been often the choice places of burial for the nobility and upper classes (Kemp and Graves 1996), it is unlikely that the individuals buried within the church were from the highest levels of York's society, but instead lower ranking gentry and modestly wealthy individuals. As St. Andrew's was in such a poor economic situation throughout this period compared with the most of the ecclesiastical churches in York, it may not have been an attractive and popular place for burial within the higher status population at York. This being said, it is unlikely that the poorest of the area's society were buried at the cemetery (Stroud and Kemp 1993), as they would not have been able to afford the burial dues.

3.3.4 St. Helen-on-the-Walls, Aldwark, York, North Yorkshire (ca. AD 1100-1550)

3.3.4.1 Historical Evidence

The church of St. Helen-on-the-Walls was founded in the 10th century in the poor parish of Aldwark. It was located within the medieval walls of York, just north-east of the Minster. Although it was known that St. Helen's was serving a small community in the Anglo-Saxon period, there was no mention of it in the Doomsday Book (Hall 1988). The first clear mention of the church was in 1197-1201 and again in the early 13th century when the parish boundaries were formed (Palliser 1980). Throughout the Medieval period the Aldwark district was dominated by the church, which both rented and used property there and was considered to be in the 'shire of the archbishop.' Although mainly owned by the church, some of the properties were owed by private citizens, specialised craftsmen and noblemen (Jones 1988).

There was intensive redevelopment of Aldwark in the 14th century. Most of this development occurred in the 1330s, with crowding of houses and narrowing of the streets to meet the demand for housing due to the Scottish wars and royal presence in the city. At the beginning of this period, the inhabitants were of modest means and the rents were some of the highest in the city, at 13s. 4d. This prosperity soon ended and the parish of St. Helen's became one of York's poorest, with individuals in occupations as cleaners, builders, porters, servants, needle workers, and possibly prostitutes. Records indicate that rents almost halved by 1342, with an even sharper decline after the Black Plague hit the city in 1349. By 1352 rents were as low as 3s. and by 1474 the rents were 2-4s. The only saving grace for those living in this district was the drastic decline of the city's population in the 14th century and the abandonment of many properties, which reduced the overcrowded condition of previous years and allowed many inhabitants to spread out into adjoining properties (Jones 1988). In the tax assessments of the parish's value in 1443, the parish ranked the lowest of seven other churches. It was ranked 25th out of 37 in the 1490s, falling to 28 of 32 by 1524. Although a poor parish, records indicate that during the period from 1389 to 1549, the interior of the church was reserved for burial of the more relatively well-off, including a gentleman, lady, priest, marshal, tiler, parchment maker, and rectors. In 1549-50 St. Helen-on-the-Walls closed its doors and was demolished. In 1589 the parish was joined to that of St. Cuthbert (Palliser 1980).

3.3.4.2 Archaeological and Osteological Evidence

St. Helen-on-the-Walls was excavated from 1973 to 1976 by the Yorkshire Archaeological Trust (YAT). During excavations, 1,041 skeletons were recovered. The cemetery and church were used for burials from the 10th century until its closure in mid 16th century by the local poor lay population. The majority of burials were from four main areas: the church, the north cemetery, south-west and south-east cemetery (Dawes and Magilton 1980). Of the total number of burials, 243 individuals were complete enough to be included in the current study, consisting of 61 subadults and 182 adults, of which 106 are male and 76 are female (see Table 3.2). In comparison to all sites included in this study, both male and female statures were the second lowest of all the included sites. The population also possessed the highest percentage of maxillary sinusitis (see Table 3.4).

3.3.5 St. Martin, Wharram Percy, North Yorkshire (Formerly East Riding of Yorkshire) (ca. AD 950-1850)

3.3.5.1 Historical Evidence

The village of Wharram Percy was situated on a plateau 18 miles east of York and seven miles south of Malton (Bell 1987). Although Wharram Percy is now famous for being a ‘deserted’ medieval village, the site had been in use from the Iron Age until the post-World War II period. Extensive excavations from 1950-1979 provided a wide knowledge of peasant rural life during the Medieval period. The earliest documentary evidence of the village is in the Doomsday Book, which describes plough-land, Wharram le Street, and two manors. Wharram Percy’s history is that of a poor village with many periods of bleak austerity. At its height in the late 13th and early 14th century, Wharram Percy was the main settlement of a group of five nucleated settlements covering 1500 acres, with the main village site being situated on 30 acres. A survey in 1368 indicates at there were many uncultivated bovates (15-acre plots of land), nine manorial plots, four free plots, and 37 villein bovates in use in Wharram Percy, and had possibly 30 houses, a manor house, a vicarage, and a church. The population was estimated to be 67 in the early 14th century and then to be 45 in 1377, 30 of which were tax-payers. The church, dedicated to St. Martin, served the wider parish consisting of 9500 acres and all five settlements. Records indicate that in 1323 the village was undergoing economic hardships, with the manor house in decline and the corn mills not in use. Only five individuals in 1297 had substantial enough assets to be listed on the tax assessment for that year. In all, Wharram Percy ranked 33 in total assets when compared with the surrounding 50 villages. The manor house was in such decline that it was considered of no value in surveys conducted in 1368, 1435 and 1458 (Beresford and Hurst 1976, 1990; Beresford 1979, 1987).

The extent of the depopulation of the countryside in the 15th century following famines, the plague, and a change to closed field agriculture is reflected in the desertion of the Wharram Percy. It is not known how badly the plague affected the village, but there are accounts of two people from the village dying of the disease. Only four houses were in use by 1517, and these were soon deserted as the inhabitants were evicted to make way for sheep farming (Beresford and Hurst 1976, 1990; Beresford 1979, 1987). In 1672 a farm named Wharram Grange, located 1.1 miles from the church, and the vicarage were the only occupied dwellings. Farms at Wharram Percy were mentioned until 1851, and the 1841 census lists three occupied houses in the area. The last occupation of the vicarage was in 1834 when it was demolished (Beresford 1979). Due to the building of a railway in the area, the 1851 census of Wharram Percy showed a rise in the number of houses to 25 with a population of 136, with two main farmsteads, two smaller houses, and 21 temporary cottages. However, by 1861 the population was reduced to only seven persons (Beresford 1987).

During the 14^{th} and 15^{th} centuries, peasant villagers lived in cruck and timber longhouses divided into three sections: a sleeping room, living room with a hearth, and a room for farm animals and agricultural implements. Later, peasants lived in smaller houses, with separate outbuildings for animal and agricultural purposes. Excavations found no accumulation of rubbish in the house nor in the yard areas, indicating that, unlike descriptions of their urban counterparts, the rural home was regularly cleaned out. Finds also indicate that, unlike the situation in urban centres, rubbish was not deposited in backyard pits (only two were found in the village), but instead it was collected and distributed over the surrounding fields (Beresford and Hurst 1990).

The parish church of St. Martin and the adjoining vicarage were situated west of the village plateau in a valley. The earliest mention of the church is in 1210-20, with the naming of a vicar. The church was founded as a timber-framed building in the mid to late 10^{th} century as a private place of worship. In the following years the parish was founded, and a new larger stone church was rebuilt on the site. The last use of the church and churchyard for burial was in 1906 and the last service was conducted in 1949 (Beresford 1987; Beresford and Hurst 1990).

3.3.5.2 Archaeological and Osteological Evidence

Excavations of the church and cemetery were conducted between 1962 and 1978, during which 687 discrete burials were uncovered (Beresford 1987; Beresford and Hurst 1990; Mays 2007). The skeletal collection is now curated by English Heritage in Portsmouth, UK. The current research included only a small sample of the total number of individuals, numbering 275, including only those deemed to be over 75% complete. Of these, 106 are subadult and 169 are adult (83 males and 86 females) and are of all phases of the cemetery (see table 3.2).

During its history, the church was rebuilt approximately 12-13 times, with six main construction phases. Burials began in the mid 11th century within the new stone church and cemetery. Burial within the church occurred mainly during the post-Medieval period, with the north and west graveyards in use until the early 16th century. There are at least four cycles of burial in the graveyard. During the period between 1570 and 1906 records indicate that at least 966 burials took place, with the wealthy favouring burial inside the church and the remaining using mainly the southern churchyard (Beresford 1987; Beresford and Hurst 1990). Although the church and cemetery were in use from the 11th to the early 20th century, the majority of burials date to the 11th to 14th century (Mays *et al*. 2007).

Wharram Percy's demography and prevalence of pathological conditions indicates that, of the populations included in this study, it suffered relatively poor health in comparison (see Tables 3.3-4). Of all the populations included in the current research, Wharram Percy had the highest juvenile mortality. It had the fourth highest percentage of juveniles below the age of 5-6 years, after populations dating to the Industrial Revolution and the poor parish of St. Helen's. The population also had relatively short statures, the Wharram Percy males being the second shortest and females the third. In addition, Wharram Percy had a considerably high rate of tuberculosis, being the third highest after Chichester and Hereford. The population also had a relatively high number of individuals with rickets and sinusitis.

3.3.6 Battle of Towton Mass Grave, Towton, North Yorkshire (AD 1461)

3.3.6.1 Historical Evidence

The War of the Roses began as a power struggle for the throne between Richard, the Duke of York, and Edmund Beaufort, the Duke of Somerset, during the reign of King Henry VI. The majority of the battles were fought between 1455 and 1487 AD. On Palm Sunday 1461 during a snowstorm a battle was fought near the town of Towton. The battle raged for 10 hours in a field six miles by three and a half miles in area. The two armies had a total of 45,000 men, consisting of noblemen, their tenantry (i.e. individuals with feudal ties or contracts of indenture), and those who simply fought for a wage. Some of the men were seasoned soldiers, i.e. livery men-at-arms or mercenaries, but many of the men who fought and died may not have been used to or trained for combat. The end of the battle saw a Lancastrian defeat, with a total of 28,000 dead on both sides, making this one of the bloodiest battles in English history (Boardman 2000; Knüsel and Boylston 2000).

3.3.6.2 Archaeological and Osteological Evidence

Thirty-eight adult males were recovered from a mass grave discovered during the building of a new garage at Towton Hall, just north of the battlefield (Fiorato *et al.* 2000). The collection is now held at the Biological Anthropology Research Centre (BARC), Archaeological Sciences, University of Bradford. Of those recovered, 31 were complete enough to be included in the current research (see Table 3.2). Osteological analysis of the collection revealed that the individuals were in relatively good health (see Tables 3.3-4). The average stature was 171.6 cm, only slightly taller than the medieval English average male height. Evidence for disease was low, with a low rate of sinusitis, joint disease, dental enamel hypoplasia, and non-specific infection; and no specific infections, neoplastic diseases (other than benign osteomata), and specific metabolic diseases. There is, however, a comparatively high prevalence of cribra orbitalia (32%) and caries (85.7%) (Boylston *et al.* 2000; Coughlan and Holst 2000; Holst and Coughlan 2000). Physically, most of the individuals were found to be of average robusticity, with a few individuals exhibiting changes indicating strenuous activity, possibly archery, from an early age (Knüsel 2000a; Rhodes and Knüsel 2005). All individuals had evidence of trauma. Further, all but one individual was found to have at least one perimortem injury. There was also a considerable amount of healed trauma, with 33% of the individuals having post-cranial trauma and 32% with cranial trauma (Novak 2000).

3.3.7 St. Wilfrid's's, Hickleton, West Riding of Yorkshire (now South Yorkshire) (c. AD 1150-ca. 1850)

3.3.7.1 Historical Evidence

St. Wilfrid's's church served the local rural parish population of Hickleton, West Riding of Yorkshire (now South Yorkshire), and is located six miles east of Doncaster and nine miles west of Barnsley on the River Dearne. It is unknown when Hickleton was first settled, but by the time of the writing of the Domesday Book, there was a Saxon village with two landlords, four villagers, 13 small holders, and 800 acres of cultivated land. Throughout the Medieval period, Hickleton remained about the same size, peaking to around 1,100 acres in 1349 (Dabell 2005). The foundations of the current church building date to 1050-1150 AD, and the earliest documentary evidence for a church in Hickleton dates to 1170-77 AD (Sydes 1984; Dabell 1999). In the early 12th century the church was associated with the Priory of St Mary Magdalene of Lund, near the village of Monk Bretton, Barnsley, and by 1386 the priory took over all administrative duties (Dabell 1999).

Hickleton was a village of prosperity until the middle to late 14th century. However, of the four churches owned by Monk Bretton Priory, St. Wilfrid's was the least valuable. With a bad harvest in the 14th century teamed with cold weather and deaths due to the plague in 1349, the church and village were in financial trouble. Poll tax records of 1428 indicate that there were less than 10 individuals living in Hickleton, down from 32 in 1379. The 15th century saw a return to prosperity, most likely due to successful sheep farming (Dabell 1999). This prosperity was also reflected in the building of a grand Elizabethan manor house, boasting 32 hearths, which had transformed the layout of the village. The late medieval village consisted of a manor house, church, rectory, and several farms or small holdings. The church survived the Reformation, but it was no longer the centre of village life, as it stopped being used as a place to transact business or as a place for sociable meetings. The church fell into disrepair under the ownership of the Queen and it was not until 1683, when the Wentworth family purchased Hickleton, that the church was refurbished. In 1829, prosperity returned to the village when Hickleton's ownership changed hands to Sir Francis Wood and his son, Charles, the first Viscount of Halifax. The remaining medieval buildings were destroyed, and a new village was created for its estate workers. By 1880 the family had upped the standards of both the church and the village (Dabell 1999, 2005).

3.3.7.2 Archaeological and Osteological Evidence

Excavations of St. Wilfrid's's took place inside the church in 1983 in advance of restorations to the building. There were 71 individuals removed from the church during excavations (Stroud n.d.), of these 25 are still above ground and are being curated at the Biological Anthropology Research Centre (BARC), Archaeological Sciences, University of Bradford. All 25 skeletons were in excellent condition and could be used for this study. The collection is comprised of nine subadults and 16 adults, eight males and eight females (see table 3.2). Individuals are from all phases of the church's use, mainly dating from the later Medieval period to the 19th century. There are relatively few pathological conditions evident in this population (see tables 3.3-4), although one female has a cleft palate and others show signs of osteoarthritis, minor injuries, and other congenital conditions (Stroud n.d.).

3.3.8 St Peter's Collegiate Church, Wolverhampton, Staffordshire, West Midlands (AD 1819-ca. 1870)

3.3.8.1 Historical Background

Settlement in Wolverhampton began in 985 AD and, by the writing of the Domesday book, settlements in the area consisted of 30 small holdings and six villages, with a population of 200. As Wolverhampton became more populated, a regular market was held from 1179. The town flourished throughout the Medieval period. Even after the 14^{th}-century plagues the town prospered, mainly due to the woollen trade. With the intensification of mining of coal and iron in the area in the 16^{th} century, Wolverhampton's economy turned to industry. The town became famous for its lock industry as early as the 17^{th} century. Other industries included jewellery making, toy making, and tin plate japanning in the 18^{th} century (Adams and Driver 2007). In the late 18^{th} century, the city's turnpikes began to be tolled, which allowed for repairs and improvements to the roads, thus increasing road transportation to and from the city (Farley 1985). During the 19^{th} century, small manufacturing was replaced by heavy industry as immigrants flooded to the city. Wolverhampton became the centre of the "Black Country" (Adams and Driver 2007). With the boom in the iron industry by 1750, the demand for coal increased dramatically. By the 19^{th} century, with improvements made in canal transport, the area processed eight million tons of coal. During the 19^{th} century over 100 coal furnaces were in regular operation in Wolverhampton at any one time (Farley 1985).

With the growth of industry also came the deterioration of living conditions. In 1750 there were 1,400 houses and a population of 7,454; by 1801 the population had reached 12,565 with 2,532 houses. Over the next decades the population of Wolverhampton grew at a rate of approximately 10,000 people per year, reaching 75,766 people by 1881 (Farley 1985; Parker n.d.). The increase in housing during the late 18^{th} century filled most of the city's green spaces and created high density back-to-back housing. In addition, the new developments were built without having to adhere to building regulations. The 18^{th}- and 19^{th}-century working class would have lived in areas where the streets were narrow and houses were dirty with poor water supply, poor to no ventilation, and stagnant pools of water and rubbish piles a common sight. Few houses in the city had underground drainage or sewers; instead, there were open drains and ditches. Although some improvements were made with the Improvement Act of 1777—such as the expansion and paving of a few streets, an end to animal slaughter in the streets, and weekly rubbish pickup—the enhancements were inadequate and only made in the centre of town. Damningly, the Rawlins Report in 1849 indicated the sanitary situation had far from been improved. It stated that, although sewers could have been cheaply installed throughout the city, this had not yet happened due to bad local planning. The poor sanitary conditions were also in evidence in the 1832 and 1849 cholera epidemics, with 578 cases (of whom 183 died) affecting mainly the poorer working class districts. Poor diet, insufficient food, and epidemics—including tuberculosis, typhoid, and scarlet fever—between 1840 and 1870 saw the highest death rates, affecting mainly the eastern working class districts (Farley 1985; Coates and Nielson 2002; Adams and Driver 2007). The Children's Employment Commission of 1843 found that many of the children of the city were "delicate, some sickly, many ill-formed, meagre, and awry (or even with incipient malformations), some badly deformed and in stature stunted" (quoted in Adams and Driver 2007: 9). Further, the 1948 Public Health Act indicated that life expectancy at birth was only 19 years old and that one in six children died before their first year (Adams and Driver 2007).

These poor and crowded living conditions in the city were reflected in overcrowding of the cemetery at St. Peter's church. St. Peter's was founded in approximately 659 AD, initially as the Abbey of St. Mary, and was rededicated to St. Peter in the 12th century. As the city's population grew, the cemetery became overcrowded and an overflow cemetery opened in 1812. In 1819 St. Peter's was granted a little more than one and a fourth acre of land near the Deanery. This new cemetery became shortly overcrowded by 1848. Relief came in 1850 when a new general cemetery (Merridale Cemetery) opened. Burials in the overflow cemeteries became limited in 1853 as the Metropolitan Interment Act prohibited any further burials in churchyards, except where an individual would be buried in an existing family tomb or plot (Coates and Nielson 2002; Adams and Driver 2007). Parish records indicate that those interred at St. Peter's church were mainly of modest means. A few of the occupations listed in burial records include a shoemaker, travelling man, bucklemaker, tiler, miller, butcher, barber, labourer, nailer, wheelwright, felt maker, brickmaker, and hatter. Many of the interred individuals were listed as coming from the workhouse or as 'poor' (Galloway 2002).

3.3.8.2 Archaeological and Osteological Evidence

One hundred and fifty-two burials from the overflow cemetery of St. Peter's Collegiate Church, Wolverhampton, were excavated in 1996 by the Birmingham University Field Archaeology Unit (BUFAU) (Adams and Driver 2007). The collection is now on loan to the Biological Anthropology Research Centre (BARC), University of Bradford, from BUFAU. Of the 152 burials, 84 skeletons were complete enough to contribute asymmetry scores for the current research. The sample consists of 24 subadults and 60 adults, 31 males and 29 females (see Table 3.2).

The burials from the overflow cemetery span a small time-frame, dating to between 1827 and 1870. The site was reported to have reached its capacity by 1860. After 1870 there are no known burials. The church's burial records and the city's census are extensive, therefore many of the interred families' backgrounds are known. Although the presence of vault burials suggests high status individuals may have been interred here, the overcrowded state of the overflow cemetery and the local poor opinion of the area made it likely not to have been a desirable place to be buried. Furthermore, many of the wealthy families in Wolverhampton already had family plots or vaults nearer to the church. The wealthiest of the poor families buried in vaults in the overflow cemetery were from the Carter family, who had occupations such as a seamstress, whitesmith, beer-house keeper, beer-retailer, and an iron brazier. One named individual from the population, James White, was a grocer and tea dealer. Other known occupations of the skeletal population were brass case lock manufacturer, screw-maker, locksmith, rule-maker, and huckster (Coates and Nielson 2002; Watt 2007). Thus, it can be assumed that economic situation of the majority of this population was of a lower status.

Results from the reported pathological and demographic analysis of the whole skeletal population also indicate that the individuals from St. Peter's overflow cemetery represent a section of the working class, many undertaking hazardous occupations. Of the subadults in the population, approximately 76% died before the age of five years (Adams and Colls 2007; Arabaolaza *et al.* 2007), giving it the highest mortality level for this age group among the populations contributing to this research (see Table 3.3-4). Overall, Wolverhampton had the second highest total juvenile mortality rate of all the populations included in the present study, and it had one of the lowest numbers of adults living beyond 45 years. There was also a high prevalence of dental enamel hypoplasia, rickets, fractures, a possible case of syphilis, and the second highest number of malignant neoplasms. There were also three amputees in the population, one of whom most likely occurred in an industrial accident (Arabaolaza *et al.* 2007).

3.3.9 Cathedral Church of St Mary and St Ethelbert (Hereford Cathedral), Herefordshire (ca. AD 680-1550)

3.3.9.1 Historical Evidence

Hereford was founded as a border garrison, on the English/Welsh border, situated close to the junction of the River Wye and Lugg in a low land basin of Herefordshire. The foundation of Hereford's church and monastic community has been accredited to both Milfrith, a member of the Mercian ruling class, and Bishop Putta in c.680 AD (Shoesmith 1974; Stone and Appleton-Fox 1996; Keynes 2000). At its beginnings, the settlement at Hereford mainly served as an important military stronghold and may have served as the capital of *Magonsaete* and then later Mercia (Russo 1998). The settlement saw many battles with and incursions from the Welsh. King Æthelberht had a royal residence near Hereford at Sutton in the late 8th century. With his death, a cult of St. Æthelberht formed and the cathedral at Hereford was thus dedicated to the late king. In the 9th century the centre of power shifted and Hereford was under direct control of the new central Anglo-Saxon Kingdom under Alfred the Great, which transformed the former frontier town into a booming city (Stone and Appleton-Fox 1996; Keynes 2000). The original town was small, spanning 50 acres, with the cathedral at its centre (Shoesmith 1974). Hereford's inhabitants during this period were a mixture of people with Anglian and Welsh backgrounds, having their own unique socio-economic structures (Keynes 2000). The first documentary evidence of the Cathedral was in 803-805 AD with mention of its bishop, Wulfheard. By the late Saxon period there were two major churches in Hereford, the Cathedral and St. Guthlac's, and at least five smaller parish churches. In the middle of the 11th century Hereford Cathedral was struggling financially and, in 1055, with Welsh and English tensions at a peak, Hereford was sacked by Saxon rebels and the Welsh and the Cathedral was destroyed (Barrow 1992).

Following the Welsh invasions, the Norman Conquest reached Hereford in 1088 (Shoesmith 1974). Medieval Hereford saw economic prosperity and growth, the town almost doubling in size to 93 acres. The Domesday Book recorded 103 men living inside and outside the walls. Also, by the time of its writing, the lands owned by Hereford Cathedral were significant, at 300 hides (Stone and Appleton-Fox 1996; Keynes 2000). This prosperity was also reflected in the building of a mint and new stone Cathedral during this period from 1107-1115, with rapid population growth after 1067. Although there was prosperity, the Cathedral's worth in the 12th century was lower than that of Lincoln, Salisbury and Wells. By 1108 Hereford Cathedral claimed exclusive burial rites for the city, which continued until 1791 when the cemetery was closed due to overcrowding. From the 12th century onwards the Cathedral cemetery served all parishes in the city, suburbs and some of the surrounding parishes; although, burials were known to take place outside the Cathedral, as evidenced by the 62 individuals buried in the graveyard of Church of St. Guthlac (Shoesmith 1980; Stone and Appleton-Fox 1996; Barrow 2000).

Hereford's prosperity was short-lived. From 1138-1140, during the civil war between Stephen and Matilda, Hereford was under siege and part of the town was burnt to the ground. The city's troubles were also reflected in a reduction of the Cathedral's and its clergy's worth between 1268-1535, which was more dire after the Black Death's arrival in 1348-9 (Shoesmith 1974; Swanson and Lepine 2000). Hereford Cathedral's wealth and influence was boosted as the Cathedral became a popular pilgrimage site with the canonisation of Thomas Cantilupe, once Bishop of the Cathedral and advisor to Edward I, in 1320. However, this respite was short-lived and the plagues brought destitution. The hardships in the town are reflected especially by the price of rents. Rents were dramatically reduced, with some not being paid at all, properties were in decay, and church records indicate that there was a lack of tenants in both their rural and urban properties. In addition, farmsteads owned by the Cathedral had halved in value by 1451 (Swanson and Lepine 2000).

3.3.9.2 Archaeological and Osteological Evidence

A small area of the cemetery to the west of the cloister of Hereford Cathedral was excavated in 1993 to make way for a new building that now houses the *Mappa Mundi*. The skeletal collection is now held at the Biological Anthropology Research Centre, University of Bradford. As the collection is yet to be published, a full demographic and pathological profile is unavailable. In total 1,129 discrete burials were uncovered dating from the late Saxon period to the early 15th century. The Saxon graveyard consisted of 21 individuals dating from the late Anglo-Saxon period to 1100. As the area is east of a stone building, it has been suggested that it was used for high status individuals. The Anglo-Saxon burials were cut by a large pit containing as many as 5,000 individuals. It is thought they were either reburied in this area during clearance for the new Norman cathedral or that they were from a charnel house that had to make way for new burials. In the late 12th century until the middle of the 16th century this area was again in use with 896 discrete burials and 189 individuals from three mass plague pits. The plague pits were dated from pottery to the late 14th and early 15th centuries (Stone and Appleton-Fox 1996). Of the 1,129 burials, a sample of 223 more complete individuals was included in the present research. Of these, 55 are subadults and 168 are adults (80 males and 87 females) of all age groups and are from all phases of the cemetery (see Table 3.2). The high fragmentation of the majority of the skeletons limited the number of measurements that could be obtained.

Hereford's exclusive burial rites suggest that individuals buried at the Cathedral would likely have been from all social ranks. However, evidence suggests that, apart from the high status Anglo-Saxon burials, the majority of the individuals represented from the excavated area may have been of middling to lower status. This is suggested by its western position, its distance from the altar, and the presence of both mass charnel and plague pits. Furthermore, throughout the Medieval period the Cathedral's monopoly over burial rites was often disputed. Parishes were known to bury wealthy and influential individuals in their local church of choice. In 1348 the Cathedral gave way and agreed that general burials in parishes were allowed, but all the proceeds from such services went to the Cathedral (Stone and Appleton-Fox 1996; Shoesmith 2000; Swanson and Lepine 2000). Therefore, those individuals buried in this area of the burial ground probably lacked the money or influence for a parish burial or a more esteemed location within the cemetery. However, these individuals may not have been at the lowest levels of society as surviving records indicate that at least in 1288 the Cathedral had an agreement with the Rector of Hampton Bishop, that permitted all those individuals with incomes less than 6s and women to be buried in that parish, but those exceeding this income would have to be buried at the Cathedral. This rite was further extended in the early 14th century as the Cathedral permitted all local parishes burial rights for children and paupers (Shoesmith 2000; Swanson and Lepine 2000).

3.3.10 Blackfriars, Gloucester, Gloucestershire (AD 1239-1539)

3.3.10.1 Historical Evidence

The town of Gloucester lies in the valley of the River Severn. It was first settled in the 1st century AD, with the founding of a fortress in 60 AD. The Romans expanded the town from 100 AD and in 577 AD the Anglo-Saxons captured the city. The late 9th

century saw the area serving as mainly an agricultural economy, but it also played an essential role in the government of Earldorman Æthelred, who was later buried in the city in 911 AD (Heighway and Bryant 1999). During the Medieval period, Gloucester continued as an administrative, agricultural, and religious centre. During the 13th century there was a large influx of immigrants, including the Dominicans. The town's economic vitality and prosperity during the 12th and 13th centuries was due to the many religious houses within the town, trade with smaller market towns, manufacturing (mainly textile), ironworking, agriculture, and frequent visits by the royal family In 1327 Gloucester was ranked 16th in wealth of all English towns and 15th in 1377. By the early 14th century, the population had reached 4,000, and the town covered 680 acres in addition to suburbs outside the walls in 1370. This prosperity appeared to continue throughout the 14th and early 15th century, despite the 1349 plague. Gloucester did not start to decline until the mid to late 15th century. This decline is reflected in the abandonment of the town by the wealthy merchant class and appeals for aid in the 1440s. At the time the population was reduced, as many as 300 houses were in decay, and much of the town's buildings and structures were in disrepair. The hardships of the town were short-lived and Gloucester was again listed 17th in wealth of all English towns in 1523 (Herbert 1988a, 1988b, 1988c, 1988d).

Blackfriars friary was founded in 1239 by the Dominicans, but it was not consecrated until 1284. The friary is situated near the south walls of the city, west of Southgate Street and east of the castle. At its height in the 14th century the friary's inhabitants numbered between 30 to 40 and the building was enlarged in 1365. However, unlike most of the city, Blackfriars saw opposite fortunes and did not seem to recover from the hardships following the plague years. By the time Blackfriars closed its doors in 1539 during the Dissolution there were only seven inhabitants (Herbert 1988b; Wiggins *et al.* 1993).

3.3.10.2 Archaeological and Osteological Evidence

A section of the Blackfriars' cemetery in the Ladybellegate Street car park, to the north of the friary, was excavated in 1991 by the Gloucester City Council Excavations Unit. A geophysical survey indicated that the cemetery is larger than what was excavated, with approximately 2,000 burials. One hundred and twenty-nine burials were recovered and are now being curated by the Biological Anthropology Research Centre at the University of Bradford (Wiggins *et al.* 1993). Of these individuals, 55 were complete enough to be included in the present research, consisting of 16 juveniles and 39 adults (21 males, 17 females, and 1 indeterminate). As the friary had only a reported maximum of between 30-40 residents and due to the presence of women and children, it is assumed that, similar to other ecclesiastical houses, Blackfriars was allowing burials of individuals from the surrounding lay population (Wiggins *et al.* 1993). The Blackfriars' skeletal population was found to have the lowest stature for both males and females of all the sites considered in this research, suggesting that these individuals many have been of low status. Although many individuals exhibited pathological conditions, Blackfriars had a lower prevalence compared with the other populations included in this study.

3.3.11 Chelsea Old Church (Formerly St. Luke's and All Saints), Chelsea, Middlesex (AD 1695-1842)

3.3.11.1 Historical Evidence

Chelsea is situated on the River Thames in the county of Middlesex, and in the 18th and

19th century it was still considered a rural village on the outskirts of London (Figure 3.3). At least by the late 19th century, Chelsea was physically connected to London and no longer rural. The village was developed in the 15th century as riverside resort for London's elite. It was not until the 18th century that the village opened up to a wider selection of the population (Croot 2004a; Insley and Croot 2004; Cowie *et. al*. 2008). The population of Chelsea more than quadrupled in size during the 19th century. In 1801 there were 11,604 residents, by 1821 it was 26,860, and by 1851 the total reached 59,881 (Croot 2004b). Throughout its history Chelsea had many wealthy residents, including Sir Thomas More, King Henry VIII, Queen Elizabeth I, viscounts, dukes, duchesses, lords, a prime minister, bishops, scholars, and renowned writers (like Thomas Carlyle). The famous Old Bun House and Don Salter's Coffee House (and museum of curiosities) attracted visitors such as King George II, Queen Caroline, King George III, Queen Charlotte, Richard Cromwell, and Benjamin Franklin (Walford 1892). Although known as an upper-class village, in 1735-7 a workhouse was opened to accommodate an increase in the number of people on poor relief. In 1781 there were 131 inmates, but by 1813-14 this increased to 197 inmates and 332 individuals on out-relief, and 5,636 on occasional relief. In addition, it was claimed that in 1817 there were over 6,000 paupers in the town (Currie 2004).

Figure 3.3: Chelsea in relation to London in 1786 (Cary 1786).

Apart from being the playground for the rich, Chelsea's economy was based mainly an agriculture and industry. The main industries in Chelsea consisted of bricklaying, brewing, dyeing, paper staining, floor-cloth production, coach transportation, silk production, porcelain crafting, and metalworking (Insley and Croot 2004). Throughout the 17th to 19th centuries Chelsea's agriculture focused on garden vegetables as they had became a new fashion for the tables of the rich and middle class. With a greater demand from the ever-expanding London for garden vegetables, a new system of farming was adapted in Chelsea. For the first time farmers in the area used manure to enrich the soil instead of letting the fields lay fallow. Although it was a profitable occupation, by 1801 only 1.6% of the population were employed in agriculture, and in 1831 it decreased to 0.3%, as land became more valuable for development than farming (Insley and Croot 2004).

The village's parish church of All Saints, commonly referred to as Chelsea Old Church, was founded in the early Medieval period and it was later rebuilt in the 1670s. In the late 17th century Chelsea Old Church was referred to as St. Luke's, a name that was attached to it until the new church building dedicated to St. Luke was opened elsewhere in the village in 1824. It was at this time that the community began to refer to the old building as Old Church (Baker 2004). All members of society would have been buried in Old Church's cemetery until 1736 when an overflow cemetery opened in another section of the town. Afterwards, those buried at Old Church would have been chiefly of higher status (Cowie *et al.* 2008).

3.3.11.2 Archaeological and Osteological Evidence

Two-hundred and ninety skeletons were recovered during excavations carried out by the

Museum of London Archaeological Service in 2000, of which 198 have been subjected to osteological analysis (Bekvalac and Kausmally 2007; Cowie *et. al.* 2008). The collection is now curated by the Centre for Human Bioarchaeology at the Museum of London. Of the burials lifted, twenty-five had coffin plates giving the name of the individual. A few of the occupations and backgrounds were known for the named individuals, including the Hand family who were founders and owners of the famous Old Bun House; the Butler family, gentlemen; T. Langfield, gentleman; John Long, esquire; William Wood, butcher and beadle; and Nicholas Adams, the bricklayer of the parish. Although the skeletal population is of a high social status, many individuals were found to be suffering from pathological conditions which affected their skeleton (Bekvalac and Kausmally 2007; Cowie *et. al.* 2008) and the average stature for males is relatively short compared with the other skeletal populations under study here (see Tables 3.3-4). However, in comparison, there was found to be a relatively low prevalence of cribra orbitalia (8.6-9.1%) and the females of Chelsea were found to be the tallest of all the included populations. In addition, apart from York Minster, Chelsea had the lowest percentage of subadults and the highest number of individuals over 45 years old (see tables 3.3-4).

Due to time constraints only small sub-sample of 52 individuals was included in the current research, of which 48 were adults (25 males and 23 females) and four were subadults (see Table 3.2). Eighteen of the individuals were named and all had known demographic information, with a few with known social status and/or occupation.

3.3.12 Hospital of SS. James and Mary Magdalene, Chichester, West Sussex (ca. AD 1118-1689)

3.3.12.1 Historical Evidence

The hospital of SS. James and Mary Magdalene, Chichester, West Sussex, was initially founded as a *leprosarium* for a small group of eight lepers, prior to AD 1118. The hospital was situated on the outskirts of Chichester, on a 10-acre plot of land. Although segregated from the city, SS. James and Mary Magdalene's would have been highly visible to travellers entering the city, as the hospital was alongside one of the main roads to the city and on a junction of two further busy roads. The founding of this hospital occurred during the chief building period of such houses in England between the 12th and 13th centuries when leprosy was at its peak. By the early to middle 14th century the number of individuals afflicted with leprosy in England decreased. This decline can partly be attributable to the famines and plague of the early 14th century, which devastated many of these hospital populations (Clay 1966; Lee 2001; Magilton 2008a, 2008b). Even at its height, life within the hospital would have been poor. Many of the 13th-century leper houses were very poor, falling apart and could barely supply 'the necessities of life,' even for those inmates of higher status (Clay 1966: 39-40). At SS. James and Mary Magdalene's, the hospital's economy depended on gifts and payments made by the Church and Crown, and through alms and charitable donations from private citizens (Magilton 2008a). .

Not everyone in the leper hospitals or buried in their cemeteries was afflicted with the disease. Many of the surrounding area's poor would also have sought the *leprosarium* as a refuge and as a place where they could receive food and board. Also, during the 13th century many *leprosarium* inmates across the country were cast out in favour of those who could pay (Clay 1966), however, it is unknown if this happened at SS. James and Mary Magdalene's. The earliest mention of a non-leper burial at SS. James and Mary Magdalene's was made at the end of the 12th century in a dispute over burial payments made for the burial of an individual's mother and father in the hospital's cemetery. In addition, the presence of women and children in the cemetery suggests it may have also been used by families of inmates and those who worked in the hospital, or that it could have been open to the local lay population (Magilton 2008a).

As a reflection of the nation-wide changes reported in statutes of 1344 and 1346, which indicate that those inmates afflicted with leprosy in these hospitals were the minority (Clay 1966), SS. James and Mary Magdalenes' status had changed to that of an almshouse in the middle of the 14th century. From this point, it is clear the brethren were accepting the poor and individuals with a range of illnesses and impairments. Following the Reformation, the hospital assumed a new function as a house for the mentally and physically handicapped. Records of 1594 indicate that the hospital's occupants were five men and six women, all being described as crippled (Magilton 2008a). In 1591 a list of inmates included 'John Pellard a diseased idiot, 30' and 'Elizabeth Vody an idiot, 17' (Page 1907: 99), and the last admission in 1685-9 was that of a 'miserable idiot' (Turner 1861; Magilton 2008a).

3.3.12.2 Archaeological and Osteological Evidence

The hospital of SS. James and Mary Magdalene's was excavated in 1986 and 1992. The skeletal collection, consisting of 373 individuals, is currently held at the Biological Anthropology Research Centre (BARC), Archaeological Sciences, at the University of Bradford. A sample of 277 individuals was deemed complete enough to be included in the current research (see Table 3.2). Of those examined, 54 are subadults and 223 are adults, of which 144 are male, 75 are females, and one is of indeterminate sex. As the sample originates from a hospital and almshouse, many of those examined have evidence of pathologies, ranging from leprosy, tuberculosis, osteoarthritis, osteoporosis, inflammatory diseases, trauma and congenital abnormalities (Lee 2001; Magilton *et al.* 2008). However, measurements from pathological bone were not included in the current research. In comparison with other sites included in this study, Chichester had the highest prevalence of rib lesions, DISH, periostitis, tuberculosis, cribra orbitalia, scurvy, neoplasms, and enamel hypoplasia. It also had the second highest prevalence of caries and fractures. However, both male and female statures are average.

Dating of individuals to either the *leprosarium* or almshouse phase is problematic as radiocarbon dates are as yet not available. Magilton (2008c) reviews several ways in which the cemetery could be dated—including the use of evidence of leprosy, pottery, secondary burials, women and children, 'ear muffs,' and coffin nails as guides—but he concludes that none of these methods lead to a satisfactory dating of the site or individuals within it. Instead, the cemetery is arbitrarily divided into four sections: A1 & 2 and B1 &2. Some conclusions can be drawn about the dating of these areas. Burials in A1 could be from any phase of the cemetery as they could be from the earliest *leprosarium* phase, or the hospital could have been segregating the later burials, separating the lepers from the poor and healthy. It is possible that Area A2 was used mainly during the first phase of the cemetery. However, the clustering and density of burials found in both A2 and B1 could indicate the presence of a tomb or significant feature that was used throughout the site's occupation. The use of the eastern part of B1 and all of B2 is considered to be the later phases of the cemetery (Magilton 2008c). For the purposes of this research Areas A1 and A2, and B1 and B2, have been combined to aid comparison of early and late use of the cemetery.

3.4 Summary

This chapter has provided an overview of the socio-economic situation and environmental conditions of the sites used in this thesis. Through the middle Anglo-Saxon to the Victorian period English society witnessed times of both prosperity and of destitution. What becomes clear is that, in many respects, the living conditions of individuals from the varying time periods were plagued with similar problems. In urban settings, comparable themes include pollution, poor sanitation, increased pathogen loads, overcrowding, increased poverty, and lack of resources. Rural England fared better in environmental conditions but, apart from the elite, individuals experienced poorer socio-economic circumstances. Rural England also constantly struggled to overcome the imbalance of resources available as the population in the more urban areas increased, while at the same time there was a steady depopulation of the countryside. Each period experienced social upheaval and reorganization—at the beginning of the Anglo-Saxon period it was the after-effects of Rome's withdrawal, and the Viking and Anglo-Saxon migrations; early Medieval times with the Norman Conquest; late Medieval period with war, plague and famine; and the post-Medieval period with the Reformation, Civil War and Industrial Revolution. Furthermore, each period saw widening social divisions between the elite and commoner.

The eleven sample populations were chosen to reflect as many levels of the differing socio-economic situations and environmental conditions as time would allow. There are sites from each of the three main historic periods, from rural and urban settings, and populations that have come from high to low social statuses. Since fluctuating asymmetry reflects disturbed development, it is an excellent biological indicator that can be used to compare previous assessments of these populations' socio-economic and health status—to assess not only the validity or strength of these associations but also to assess the relationships between asymmetry (both DA and FA) and overall health of the populations. This type of bioarchaeological approach also allows consideration of how we divide the past into archaeological categories, such as time periods, settlement classification, demographic make up, and social-economic status.

Chapter Four

Methods

4.1 Assessment of Demography

Estimation of sex was only undertaken for adult skeletons. Adult sex was determined through as many pelvic (Phenice 1969; Stewart 1979; Buikstra and Ubelaker 1994; Bass 1995) and cranial (Stewart 1979; Buikstra and Ubelaker 1994; Bass 1995) morphological traits as were observable. Further, metrical assessment of sex (Krogman 1962; Stewart 1979; Bass 1995) was used when morphological characteristics were either unobservable or indeterminate.

Age-at-death was determined for subadults through assessment of dental development (Moorrees *et al.* 1963a, 1963b; Smith 1991), long bone lengths (Maresh 1970; Scheuer *et al.* 1980), and epiphyseal fusion (Scheuer and Black 2000). In order to facilitate comparisons subadults were then separated into four broad age categories: foetal to infant (F-I) for those prenatal to 12 months of age, early childhood (EC) for individuals of 1-6 years of age, late childhood (LC) for those of 7-12 years of age, and adolescent (AD) for those 13-17 years at age-at-death.

Age-at-death for adults was determined through changes to the pubic symphysis (Brooks and Suchey 1990), auricular surface (Lovejoy *et al.* 1985), dental attrition (Miles 1962; Brothwell 1981), and cranial suture closure (Meindl and Lovejoy 1985). Again, in order to facilitate comparisons, adults were then divided into three broad age categories: young adult (YA) for 18-25 years of age-at-death, middle adult (MDA) for those of 26-45 years of age, and mature adult (MA) for those individuals over 46 years of age-at-death.

4.2 Measurements

A comprehensive selection of measurements from throughout the skeleton was chosen in order to evaluate differences in developmental stability and to reveal traits ideal for detecting fluctuating and directional asymmetries in archaeological human remains. A range of bilateral cranial and post-cranial measurements were taken for both the right and left sides (Table 4.1.). Each measurement was taken using digital sliding calipers or spreading calipers and recorded to the nearest 0.1mm, or taken using an osteometric board and recorded to the nearest 1mm, where appropriate. Measurements are based on standard cranial osteometric points and previously defined cranial and postcranial measurements (Howells 1973; Steele and Bramblett 1988; Moore-Jansen *et al.* 1990; White and Folkens 1991; Bass 1995; Storm 2001), except those created specifically for this study. References to all craniometric points are defined in Appendix 1. For a complete description of each measurement refer to Appendix 2. Measurement coding used for this study can be found in Table 4.1 and Appendix 2. (For easy reference refer to the pull-out table located at the back of Volume 1). In order to ensure consistency all measurements were taken by the author. Any measurements taken from obviously pathological material were noted and separated for future comparisons and were not included in this study. Where an element was fragmentary or affected by taphonomic change, measurements were completed only if they could be confidently taken.

Table 4.1 Measurements taken. (M-L=medio-lateral, A-P=antero-posterior, S-I=supero-inferior, SA=subadult measurement only, for cranial abbreviations see Appendix 1.)

Measurement	Code	Age Groups
Cranium	C	
Breadth: orbit	COBB	Adult
Height: orbit	COBH	Adult
Chord: n-or	CNOR	Adult
Chord: fmt-n	CFMTN	Foetus to Adult
Chord: fmt-ns	CFMTNS	Adult
Height: malar	CMAH	Foetus to Adult
Chord: ecm-intermaxillary suture	CECMIS	Early Childhood to Adult
Chord: fmt-b	CFMTB	Early Childhood to Adult
Chord: b-zo	CBZO	Adult
Length: mastoid process	CMPL	Early Childhood to Adult
Breadth: mastoid process	CMPB	Early Childhood to Adult
Height: mastoid process	CMPH	Adult
Chord: ms-ast	CMSAST	Early Childhood to Adult
Length: digastric groove	CDGL	Early Childhood to Adult
Length: occipital condyle	COCL	Foetus to Adult
Chord: o-po	COPO	Adult
Chord: ba-po	CBAPO	Adult
Chord: n-ms	CNMS	Adult
Chord: b-po	CBPO	Adult
Chord: b-ast	CBAST	Adult
Chord: l-fmt	CLFMT	Adult
Chord: l-ast	CLAST	Adult
Mandible	M	
Length: mandible	MAL	Foetus to Adult
Maximum height: ramus	MRH	Foetus to Adult
Maximum breath: ramus	MXRB	Foetus to Adult
Minimum breadth: ramus	MIRB	Foetus to Adult
Clavicle	CV	
Maximum length	CVML	Foetus to Adult
Maximum diameter: midshaft	CVXMS	Foetus to Adult
Minimum diameter: midshaft	CVIMS	Adult
Maximum width: acromial end	CVWA	Foetus to Adult
Maximum width: sternal end	CVWS	Foetus to Adult
Maximum depth: medial curve	CVMC	Early Childhood to Adult
Maximum depth: lateral curve	CVLC	Early Childhood to Adult
Scapula	S	
Length: glenoid fossa	SGL	Foetus to Adult
Breadth: glenoid fossa	SGB	Foetus to Adult
Maximum length: acromion	SAL	Foetus to Adult
Maximum length: coracoid process	SCL	Adult
Humerus	H	
Maximum length	HML	Foetus to Adult
Maximum diameter: midshaft	HXMS	Foetus to Adult
Minimum diameter: midshaft	HIMS	Foetus to Adult
Maximum diameter: deltoid tuberosity	HDT	Early Childhood to Adult
S-I diameter: head	HSIH	Early Childhood to Adult
A-P diameter: head	HAPH	Adult
Breadth: epicondylar	HEB	Adult
Maximum M-L width: SA distal end	HSMLD	Foetus to Adolescent
Maximum M-L width: SA proximal end	HSMLP	Foetus to Adolescent
Length: greater tubercle	HGT	Early Childhood to Adult

Table 4.1 Continued.

Measurement	Code	Age Groups
Radius	R	
Maximum length	RML	Foetus to Adult
Maximum diameter: midshaft	RXMS	Foetus to Adult
Minimum diameter: midshaft	RIMS	Foetus to Adult
Maximum diameter: head	RGH	Foetus to Adult
M-L width: SA distal end	RSMLD	Foetus to Adolescent
M-L width: distal end/epiphysis	RMLD	Early Childhood to Adult
Ulna	U	
Maximum Length	UML	Foetus to Adult
Physiological length	UPL	Early Childhood to Adult
Maximum diameter: midshaft	UXMS	Foetus to Adult
Minimum diameter: midshaft	UIMS	Early Childhood to Adult
Height: radial notch	URN	Foetus to Adult
Width: olecranon	UOW	Foetus to Adult
Height: Coronoid	UCH	Foetus to Adult
Metacarpals	MC#	
MC1: Maximum length	MC1L	Early Childhood to Adult
MC2: Maximum length	MC2L	Early Childhood to Adult
MC3: Maximum length	MC3L	Early Childhood to Adult
MC4: Maximum length	MC4L	Early Childhood to Adult
MC5: Maximum length	MC5L	Early Childhood to Adult
Sacrum	SZ	
Minimum breadth: ala	SZAB	Early Childhood to Adult
A-P width: ala	SZAW	Adult
Maximum A-P width: auricular surface	SZAPA	Adult
Maximum S-I length: auricular surface	SZSIA	Adult
Height: body of S1	SZS1	Early Childhood to Adult
Os coxae	OC	
Height/SA iliac height	OCH	Foetus to Adult
Breadth: ilium	OCIB	Foetus to Adult
Length: pubis	OCPL	Adult
Length: ischium	OCIS	Foetus to Adult
Height: acetabulum	OCAH	Adult
Height: auricular surface	OCASH	Foetus to Adult
Breadth: auricular surface	OCASB	Foetus to Adult
Femur	F	
Maximum Length	FML	Foetus to Adult
Maximum diameter: midshaft	FXMS	Foetus to Adult
Minimum diameter: midshaft	FIMS	Foetus to Adult
Maximum diameter: subtrochanteric	FXST	Foetus to Adult
Minimum diameter: subtrochanteric	FIST	Foetus to Adult
Breadth: Epicondylar/distal epiphysis	FEB	Early Childhood to Adult
Maximum length: lateral epicondyle	FLE	Early Childhood to Adult
M-L width: SA distal end	FSMLD	Foetus to Adolescent
Maximum A-P diameter: head	FAPH	Early Childhood to Adult
Maximum S-I diameter: head	FSIH	Early Childhood to Adult
Maximum width: proximal end	FMLP	Foetus to Adult
Tibia	T	
Maximum length	TML	Foetus to Adult
Maximum diameter: nutrient foramen	TXNF	Foetus to Adult
Minimum diameter: nutrient foramen	TINF	Foetus to Adult
Maximum M-L breadth: SA distal end	TSMLD	Foetus to Adolescent

Table 4.1: Continued.

Measurement	Code	Age Groups
M-L width: distal end/epiphysis	TMLD	Early Childhood to Adult
Maximum M-L breadth: SA proximal End	TSMLP	Foetus to Adolescent
M-L width: proximal end/epiphysis	TMLP	Early Childhood to Adult
A-P diameter: medial condyle	TMC	Early Childhood to Adult
A-P diameter: lateral condyle	TLC	Early Childhood to Adult
Calcaneus	CZ	
Maximum length	CZL	Early Childhood to Adult
Maximum breadth	CZB	Early Childhood to Adult
Maximum height	CZH	Early Childhood to Adult
Talus	TZ	
Maximum length	TZL	Early Childhood to Adult
Maximum breadth	TZB	Early Childhood to Adult
Maximum height	TZH	Early Childhood to Adult
Metatarsals	MT#	
MT1: Maximum length	MT1L	Early Childhood to Adult
MT2: Maximum length	MT2L	Early Childhood to Adult
MT3: Maximum length	MT3L	Early Childhood to Adult
MT4: Maximum length	MT4L	Early Childhood to Adult
MT5: Maximum length	MT5L	Early Childhood to Adult

Some of the measurements taken during data collection were excluded from further analysis. Reasons for exclusion include: small sample size; measurements that were only obtainable unilaterally; the method for taking measurements could not be interpreted by a second observer; and difficult or awkward measurements that, although they exhibited low to moderate measurement error, they were found statistically to have numerous population outliers that were caused by measurement error (see electronic appendices). The results from tests for measurement error and normality tests for these excluded measurements can also be found in the electronic appendices. Subadult measurements excluded for small sample size include: orbital height, orbital breadth, *nasion-orbitale*, *frontomalare-nasospinale*, height of the mastoid process, *basion-asterion*, *lambda-frontomalare*, *lambda-asterion*, maximum length of the coracoid process of the scapula, breadth of the epicondyle of the humerus, and acetabular height. All tarsal measurements were removed for the age group foetal to infant due to low numbers of recordable measurements. The measurements greatest breadth of the alae and body of the sacrum were not used as they are not bilateral measurements. Other measurements removed for all age groups include: corpus length of the mandible; breadths of the anterior and posterior articular surfaces of the humerus; maximum diameter at the nutrient foramen of the ulna; maximum and minimum midshaft diameters of the metacarpals and metatarsals; maximum height and width of the pubic symphyseal face; the least antero-posterior and supero-inferior diameters of the femoral neck; the medio-lateral width of the distal tibia; and antero-posterior widths of the proximal and distal ends of the subadult humerus, the distal end of the subadult radius, distal end/epiphysis of the radius, distal end of the subadult femur, the distal and proximal ends of the subadult tibia, and the distal and proximal ends/epiphyses of the tibia.

All measurements from adults and subadults were separated throughout the analysis and not pooled. Although the methods in recording and analysis are similar, the measurements for the two groups are not necessarily the same, due to the differing stages of bone development. Moreover, statistically, many of the asymmetry scores from these two groups were significantly different (see Sections 5.5.3 and 5.6.3). This being the case, for ease of data collection, measurements taken from all individuals were recorded into three separate excel spreadsheets depending on ontogenetic stages (see Appendix 3). The first division consists of age ranges from prenatal to the first month of life. At this stage most of the epiphyses are either absent or too small to measure. In addition, the cranial bones of these individuals tend to be fragmentary and affected by taphonomic changes as they are very thin. This fragility limited the included measurements for this stage to 48. The second category is that of those individuals from early childhood to early adolescence. This group includes individuals with unfused epiphyses, which were treated as separate elements; 87 measurements were included in this study. The final subdivision consists of those individuals in their late adolescence to mature adults. This group includes individuals with fully fused elements or having epiphyses that have reached their adult size, and can be articulated with the diaphysis with little difficulty. This is the largest of the three groups, with 101measurements included in this study.

4.3 Asymmetry Formulae

4.3.1 Directional Asymmetry

The most basic form of statistical analysis used in this study was the direct comparison of right and left sides of each trait, correcting for trait size. A log transformation formula was used:

$$DA1=\ln(R_j/L_j)$$

where R_j and L_j are the measurements taken on both the right and left sides for each trait (Palmer 1994; Palmer and Strobeck 2003). If a result was negative, the trait was recorded as being left-sided. If the number was positive, it was considered as favouring the right. Results are reported either to the 0.001 or as a percentage. This formula is directly comparable to other published data that use the formula (cf. Palmer and Strobeck 2003: 290-294):

$$DA= (R-L) / [(R+L)/2].$$

4.3.2 Fluctuating Asymmetry

Fluctuating asymmetry scores were based on formulae suggested by Palmer and Strobeck (2003). To allow for comparisons between measurements of differing trait sizes, each individual trait's fluctuating asymmetry score was calculated using the log transformation of the standard asymmetry formula:

$$FA8=|\ln(R_j/L_j)|$$

where R_j and L_j are the measurements taken on both the right and left sides for each trait (Palmer 1994; Palmer and Strobeck 2003). As with DA1, FA8 results are reported to the 0.001 as FA scores represent a percentile of the asymmetry based on the trait's size. This formula is directly comparable to other published data that use the formula (cf. Palmer and Strobeck 2003: 290-294):

$$FA2= |(R - L)| / [(R+L)/2].$$

4.3.3 Formulae of Multiple Traits

The data was then analyzed for each individual by an asymmetry index for multiple traits (see table 4.2) calculated using the formula:

$$DA_m==\sum \ln(R_j/L_j)/T \text{ (after Palmer and Strobeck 2003),}$$

$$FA17=\sum|\ln(R_j/L_j)|/T \text{ (Palmer and Strobeck 2003),}$$

where R_j and L_j are the measurements of the right and left side of each trait and T is the total number of traits. Although indices are discussed to some extent, the main focus of this research is on single traits. As discussed in Chapter 2, there have been found to be low correlations between the levels of FA in one trait when compared with another. This is mainly due to each trait having different sensitivities to stress, the nature of each stress, and the buffering process favouring symmetry in some traits at the expense of others (Van Valen 1962; Gangestad and Thornhill 1999; Nijhout and Davidowitz 2003).

Table 4.2: Asymmetry indices for multiple traits. (*Not a subadult measurement/ index, **not an adult measurement).

Indices	Measurements included
Cranium	All cranial measurements
Cranium: Orbit*	COBB, COBH, CNOR
Cranium: Facial	CFMTN, CFMTNS*, CMAH, CECMIS, CFMTB, CBZO*
Cranium: Temporal	CMPL, CMPB, CMBH*, CMSAST, CDGL
Cranium: Base*	COCL, COPO, CBAPO, CNMS
Cranium: Vault*	CBPO, CBAST, CLFMT, CLAST
Mandible	All mandibular measurements
Clavicle	All clavicular measurements
Scapula	All scapular measurements
Humerus	All humeral measurements

Table 4.2: Continued.

Indices	Measurements included
Radius	All radial measurements
Ulna	All ulnar measurements
Metacarpals	MC1-MC5 lengths
Pelvic girdle	All pelvic measurements
Sacrum	All sacral measurements
Os coxae	All measurements of the *os coxae*
Femur	All femoral measurements
Tibia	All tibial measurements
Tarsals	All measurements of the talus and calcaneus
Metatarsals	MT1-MT5 lengths
Upper Limb	All measurements of the humerus, radius, and ulna
Lower Limb	All measurements of the femur and tibia
Upper long bone lengths	HML, RNL, UML
Lower long bone lengths	Maximum lengths of the femur and tibia
Midshafts	HXMS, HIMS, RXMS, RIMS, UXMS, UIMS, FXMS, FIMS, TXNF, TINF
Upper limb midshafts	HXMS, HIMS, RXMS, RIMS, UXMS, UIMS
Lower limb midshafts	FXMS, FIMS, TXNF, TINF
Shoulder	CVWA, SGL, SGB, SAL, SCL*, HSIH, HAPH, HGT
Elbow	HEB*, HSMLD**, RGH, URN, UOW, UCH
Sacro-iliac joint*	SZAPA, SZSIA, OCASH, OCASB
Hip	OCAH*, FAPH, FSIH, FMLP
Knee	FEB, FSMLD**, FLE, TMLP,MLP**, TMC, TLC

4.4 Ensuring Data Integrity

4.4.1 Initial Data Inspection

The raw data was initially inspected for any anomalous measurements and for population outliers that were due to measurement error and not to true asymmetry. This was accomplished through an inspection of all individuals with extreme asymmetry scores. All high to extreme levels of asymmetry scores were checked by comparing data with a photographic record of all individuals exhibiting asymmetry. At least ten of the highest negative (left side dominant) and ten of the highest positive (right side dominant) measurements were scrutinized. If uncertainty still remained, then the material was re-measured, where available. If a measurement was found to be in doubt and could not be photographically verified or re-measured, then it was removed from further analysis.

4.4.2 Tests for Outliers

Both raw (R-L) and FA8 scores for each measurement were subjected to the Grubb's test statistic (T_G) for outliers:

$$T_G=(X_i-\mu)/SD,$$

where X_i is the observed value of the potential outlier, μ is the population mean, and SD is the standard deviation (Palmer and Strobeck 2003). All outlier tests were processed by the online addition of GraphPad Software's Outlier Calculator (http://graphpad.com/quickcalcs/Grubbs1.cfm). All adolescents that had partially fused long bones were tested as young adults, while those which still remained unfused were tested with the subadults. Any significant outliers ($P<0.05$) were subsequently inspected for flaws in data collection and were subjected to further examination for taphonomic alteration or obvious traumatic injury to ensure these were true population outliers. These true population outliers were removed from further calculations of asymmetry and were analysed separately. Any outliers suspected to have resulted from measurement error were removed from further analysis.

4.4.3 Measurement Error

Due to the small values, asymmetry scores must be tested for measurement error (ME) before any significance testing can occur (Palmer 1994; Swaddle *et al.* 1994; Møller and Swaddle 1997; Palmer and Strobeck 1997; Whitlock 1998; Palmer and Strobeck 2003). In this study, both a Technical Error of Measurements (TEM) and an ANOVA of sides by individuals interaction was undertaken to ensure that measurements were both repeatable and that the between-side differences were greater than the ME. All statistics for this analysis were calculated using Microsoft Excel, except for the ANOVA which was conducted using STATISTICA 6.1. As the sample size was large and the measurements numerous, not every measurement was taken twice; instead, a sub-sample of each element was selected to test for measurement error. To further ensure minimal ME, all initial measurements were taken at least twice where a high asymmetry value was computed, and the mean was recorded throughout the data collection process.

4.4.3.1 Intra-Observer Error: Technical Error of Measurements

Technical Error of Measurements (TEM), or Measurement Error of the Method, assesses the magnitude of error when a measurement is taken on only one side. It should be noted that this technique does not assess the error in asymmetry, i.e. the error in right and left side differences, but rather, it assesses the error produced by measurement application on only one side. See section 4.4.3.2 for a discussion of error in asymmetry scores. TEM was assessed for adults and subadults separately by taking all measurements on a small sub-sample of individuals on both right and left sides of each element (thus doubling the sample size). For adults, the measurements were repeated on at least ten different occasions, at least one week apart. Repeated measurements on subadults, on the other hand, were limited due to availability of complete juvenile material and time constraints (see electronic appendix for specific number of repetitions for each trait). Differences between the measurements were derived using the formula:

$$\text{TEM} = \sqrt{\left(\sum_{1}^{N} \left(\left(\sum_{1}^{K} M^2\right) - \left(\sum_{1}^{K} M^2/K\right)\right)/N(K-1)\right)}$$

where M is the measurement, K is the number of replicated measurements, and N is the number of individuals (Mueller and Martorell 1988; Ulijaszek and Kerr 1999). Levels of significance were assessed by the formula:

$$p = (\text{TEM}^2/\text{SD}^2)$$

where SD is the studied population's standard deviation. To assess the percentage of accuracy for each measurement, the coefficient of reliability was calculated using the formula:

$$R = 1 - (TEM^2/SD^2)$$

where the SD is the standard deviation of the studied population. The standard for acceptable amount of ME using the TEM calculation has been evaluated to be R>95% (Ulijaszek and Kerr 1999).

4.4.3.2 Intra-Observer Error: Measurement Error of Asymmetry

As the above test for measurement error only assesses the amount of error on one side of a trait, it is necessary to conduct a second and more crucial test to assess measurement error in the asymmetry scores. This is achieved though a two-way ANOVA procedure of a side by individual interaction. This calculation assesses if the ME is smaller than the between-side differences measured, which will in turn indicate whether the asymmetry score is measuring more than just ME (Palmer and Strobeck 1986; Palmer 1994; Fields *et al.* 1995; Merilä and Björklund 1995). Again, as subadults and adults are at different stages of development, and because they were found to have significantly different asymmetry values (see Sections 5.5.3 and 5.6.3), they were tested separately. If a measurement was found to have significant levels of asymmetry relative to measurement error, then it was removed from further analysis. The percentage of ME within each asymmetry measurement was calculated as:

$$ME3 = MS_m / MS_{interaction} \text{ X } 100$$

where $MS_{interaction}$ is the sides by individual MS and MS_m is the measurement error as measured by the variance of repeat measurements, from a two-way ANOVA (Palmer and Strobeck 1986, 2003). Repeatability was also calculated for each measurement by the equation:

$$ME5=\frac{MS_{interaction}-MS_m}{MS_{interaction}+(n-1)MS_m}$$

where $MS_{interaction}$ is the sides by individual MS and MS_m is the measurement error as measured by the variance of repeat measurements, from a two-way ANOVA, and with repeatability results ranging from -1 to +1 (Palmer and Strobeck 1986, 2003). Although the above formula provides an indication of repeatability of an asymmetry score, the main importance of testing for a ME in asymmetry measurements is that the genuine between side differences are large enough to detect even with moderate ME, that is, the $MS_{interaction}$ is significant. Unfortunately, at the present time, there is not a standard level of acceptable ME5 repeatability percentages as there is with the TEM (Palmer 2007, pers. comm.). Although if the MS between sides and individual interaction is significantly higher than ME, a measurement is acceptable for further inclusion in asymmetry studies; however, caution should still be observed when the repeatability of a measurement is low as this reflects the extent of ME variance within the measured asymmetry (Palmer 1994).

4.4.3.3 Inter-Observer Error

Although all measurements included in this study were taken by the author, an inter-observer error was undertaken to examine the level of reproducibility by external observers. The observers used in this study had varying degrees of experience with metrical analysis of human remains. Unfortunately, it was not possible in the scope of this study to include an inter-observer who had advanced or expert experience with taking unilateral and bilateral measurements on human remains. Both Observer 1 and Observer 2 had limited previous experience with obtaining bilateral and unilateral measurements, and both had knowledge of the anatomy of human remains, while Observers 3 and 4 had no previous human bone or measurement experience. Each observer was assigned different adult specimens and was asked to take the measurements based solely on descriptions from Appendix 2. Observers 1 and 2, with the most experience, were asked to take the more difficult measurements, including those of the skull, tibia, *os coxae* and sacrum, while the remaining more straight-forward measurements were taken by Observers 3 and 4. Both TEM and measurement error of asymmetry were conducted for each observer separately and then in comparison with the author's original measurements using the same skeletons used in the intra-observer error test. As each observer's error was calculated using only one repeat of their first measurement, the formula for TEM was calculated as:

$$TEM= \frac{\sqrt{\sum(d_i^2)}}{2n}$$

where d_i is the difference between replicated measurements and n is the number of individuals in the sample (Dahlherg 1940; Knapp 1992). Both the coefficient of reliability (R) and significance levels (p) of the TEM were calculated as in section 4.4.3.1 and the measurement error of asymmetry was calculated following the procedure in section 4.4.3.2.

4.4.4 Normality and Antisymmetry Tests

Normality and antisymmetry were tested through the Kolmogorov-Smirnov (K-S) test and the analysis of skew and kurtosis using Microsoft Excel and WinSTAT 2007.1 for Excel following procedures set out by Palmer and Strobeck (1986; 1992; 2003). Tests for departures from normality were conducted on all sub-samples (i.e. specific to site, age, and sex) and larger pooled samples for adults and subadults. Statistical tests were conducted after all outliers had been removed.

4.4.5 Effects of Directional Asymmetry on Interpreting Fluctuating Asymmetry Data

As has been demonstrated in various studies (see Chapter 2), humans exhibit directional asymmetry in many areas of the body, especially the skull, clavicle, and humerus. Therefore, before an analysis of fluctuating asymmetry can be conducted, a test should be undertaken to discover if DA is a significant factor in departures from ideal FA. All DA1 scores were tested by one-sample t-tests of the mean of (R-L) against zero to assess the significance of directional asymmetry for each trait (Palmer 1994; Storm 2001; Palmer and Strobeck 2003). Further, for each measurement a comparison of mean (R-L) was conducted and the average deviation about the mean (R-L) was evaluated using the formula:

$$FA4a=0.798\sqrt{Var(R\text{-}L)}.$$

If a trait's average variation around mean (R-L) was larger than that mean, then the trait is argued to be exhibiting mainly developmental instability (Palmer and Strobeck 2003).

4.5 Population Comparison Statistics

Individuals were separated into comparison groups based on sex, age, site, settlement, and period. Subadults and adults were considered separately throughout the analysis. Comparisons of sex excluded any individuals that were indeterminate. Age was broken into three separate comparison groups including age group (adults versus subadults), subadult age (FI, EC, LC, and AD), and adult age (YA, MDA, and MA). All individuals were also compared by specific archaeological site. Additionally, individuals were separated into rural and urban settlement types to assess the affects of urbanisation. The *leprosarium*/almshouse population is included for a direct comparison between the other settlements and a population that is known to have been under increased environmental stress. Individuals from urban settlements include those from Blackfriars, Fishergate, Hereford, St. Helen's, Wolverhampton, and York Minster. Those individuals from rural settlements include Chelsea, Hickleton, and Wharram Percy. The *leprosarium*/almshouse settlement type is represented by individuals from Chichester. Towton was excluded from this comparison as the individuals are from a mass grave from a battle site and were buried outside their normal settlement region. Finally, to judge differences between the periods all skeleton with a known date (through statigraphy, finds, historical record, or radiocarbon date) were placed into the categories Anglo-Saxon, Medieval and post-Medieval periods. The Anglo-Saxon grouping includes individuals from Fishergate Period 4, Hereford, Wharram Percy, and York Minster. The medieval grouping includes individuals from Blackfriars, Chichester, Fishergate Period 6, Hereford, Hickleton, St. Helen's, Towton, Wharram Percy, and York Minster. Those individuals classified as post-medieval come from Chelsea, Hickleton, Wharram Percy, Wolverhampton, and York Minster.

As many of the measurements were found to violate the assumption of normality (see Section 5.4), a nonparametric Kruskal-Wallis analysis of variance (ANOVA) test was used to calculate differences in directional and fluctuating asymmetries between comparison groups, apart from the categories sex and age group, which were calculated using Mann-Whitney *U*-tests. Post-hoc tests were conducted for all measurements and indices using Siegel and Castellan's (1988: 213-215) 'multiple comparisons of mean ranks for all groups' tests. Only significant post-hoc tests will be reported in the following chapter. All non-significant post-hoc test results are reported in the electronic appendix. Measurements with sample sizes of less than five individuals were removed from comparisons. To analyze differences in the number of outliers between sub-samples, the chi-squared test was undertaken. All of these statistical analyses were conducted using Statistica 6.1.

The level for testing statistical significance for all tests was set at $p<0.05$. A conservative sequential Bonferroni adjustment for multiple comparisons was conducted for each statistical test using the following formulae:

$$\alpha=(0.05/k),$$

$$\alpha=(0.05/k-1),$$

where k is the number of tests (Holm 1979; Rice 1989). Results that remained significant after a Bonferroni adjustment are noted in Chapter 5 and reported in the electronic appendix. However, to avoid the probability of type-2 errors, interpretations of significant results were made based on an unadjusted significance level of $p<0.05$ (Perneger 1998; Moran 2003) (see Chapter 6.1.1 for further discussion).

Chapter Five

Results

5.1 Introduction

The following chapter consists of results from initial data integrity tests and analysis of directional asymmetry, fluctuating asymmetry, and population outliers. Results from tests to ensure data integrity—including Grubb's outlier tests, measurement error, and normality and antisymmetry tests—are presented in Sections 5.2-5.4. Analysis of directional asymmetry and fluctuating asymmetry consists of descriptive statistics and Kruskal-Wallis and Mann-Whitney *U* tests for the total population and then comparisons of specific groupings, including sex, age-at-death, archaeological site, settlement type, and period (Sections 5.5-5.6). In addition, Section 5.5.7 covers the effects of directional asymmetry on the interpretation of fluctuating asymmetry data. Finally, results from chi-square tests for differences between population outliers for groupings of age-at-death, sex, site, settlement type and period are reported in Section 5.7. Only significant differences are reported in this chapter for the majority of the sections; all non-significant comparisons can be found in the appendices in Volume 2 or in the electronic appendix. The data presented in the following results section should be used in conjunction with the code key for measurement abbreviations (see code sheet insert located at the back of this thesis).

5.2 Grubb's Outlier Test

Grubb's Outlier tests found that, of the total measurements taken from individuals from all studied populations, 830 measurements were true population outliers (after outliers from measurement error were removed) (see Appendix 4). Of these significant outliers, 600 were from the adult population and 230 from the subadult population. After a sequential Bonferroni adjustment, there were 130 adult and 43 for subadult outliers. All outliers were removed from further analyses of directional and fluctuating asymmetry as suggested by Palmer (1994) and Palmer and Strobeck (2003), and they will be handled separately in Section 5.6. The exclusion of outliers was based on an alpha level set at $p<0.05$ as many measurements disregarded as outliers after a Bonferroni adjustment were found on second examination to be true population outliers (see Chapter 6.1.1 for further discussion).

5.3 Measurement Error

5.3.1 Intra-Observer Error: TEM

All measurements included in this study were found to have a coefficient of reliability of over 97% in adult and 98% in subadult measurements (see Tables 5.1-2), therefore, all measurements taken were deemed accurate and were included in further analyses. The only adult measurement that had an accuracy lower than 98% was COBB ($p<0.026$, R=0.974). The next lowest measurements for adults include TZB (p=0.0212, R=0.9788), CNOR (p=0.02, R=0.9797), and CFMTN (p=0.019, R=0.981). The measurements with the lowest accuracy for subadults were CVXMS (p=0.016, R=0.9843), RIMS (p=0.0152, R=0.9848), and UIMS (p=0.0123, R=0.9877). In contrast, length measurements had the highest accuracy for adults, with humeral length being the most accurate (p<0.0002, R=0.9999) followed by MC2 length, femoral length, and MC3 length (all at p<0.0002, R=0.9998). Measurements for subadults with the highest accuracy include the lengths of the femur (p<0.0001, R=0.99999), the humerus (p<0.0001, R=0.99995), and the clavicle (p<0.0001, R=0.99992).

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Table 5.1: Technical Error of Measurements (TEM) for intra-observer error for the adult population.(*p significant after a Bonferroni adjustment)

Measurement	N	TEM	SD	P	R	Measurement	N	TEM	SD	P	R
COBB	22	0.279276	1.748157	0.025521	0.974479	CVWS	20	0.190817	3.422026	0.003109	0.996891
COBH	22	0.26383	1.914303	0.018994	0.981006	CVMC	20	0.448559	3.250945	0.019038	0.980962
CNOR	22	0.365224	2.561532	0.020329	0.979671	CVLC	20	0.328033	2.981228	0.012107	0.987893
CFMTN	22	0.350951	2.568485	0.01867	0.98133	SGL	20	0.388987	3.479813	0.012496	0.987504
CFMTNS	20	0.231697	3.336485	0.004822	0.995178	SGB	20	0.209881	2.760147	0.005782	0.994218
CMAH	21	0.298071	2.723394	0.011979	0.988021	SAL	20	0.315057	6.573537	0.002297	0.997703
CMPL	21	0.357963	3.239085	0.012213	0.987787	SCL	20	0.238723	3.93303	0.003684	0.996316
CMPB	22	0.376762	3.744691	0.010123	0.989877	HML	20	0.248328	20.53319	0.00015*	0.999854
CMPH	20	0.324405	2.725755	0.014165	0.985835	HXMS	20	0.263618	2.165748	0.014816	0.985184
CMSAST	20	0.221685	4.344566	0.002604	0.997396	HIMS	20	0.157339	1.957416	0.006461	0.993539
CDGL	22	0.41291	3.415332	0.014617	0.985383	HDT	20	0.291776	2.312308	0.015922	0.984078
COCL	20	0.197259	2.427052	0.006606	0.993394	HSIH	20	0.21914	3.910862	0.00314	0.99686
CECMIS	20	0.282459	2.27029	0.015479	0.984521	HAPH	20	0.241419	3.454448	0.004884	0.995116
COPO	22	0.394373	3.824884	0.010631	0.989369	HEB	20	0.096061	5.170292	0.00035*	0.999655
CBAPO	22	0.358081	3.4281	0.010911	0.989089	HGT	20	0.287817	3.685854	0.006098	0.993902
CFMTB	22	0.411329	4.840786	0.00722	0.99278	RML	20	0.374166	17.28194	0.00047*	0.999531
CBPO	22	0.401386	5.512043	0.005303	0.994697	RXMS	20	0.177811	1.748966	0.010336	0.989664
CBZO	22	0.425215	5.404737	0.00619	0.99381	RIMS	20	0.157198	1.205658	0.017	0.983
CNMS	20	0.362859	5.899875	0.003783	0.996217	RGH	20	0.181613	2.092943	0.00753	0.99247
CBAST	20	0.321455	5.97655	0.002893	0.997107	RMLD	20	0.244926	2.744053	0.007967	0.992033
CLFMT	20	0.381517	6.519245	0.003425	0.996575	UML	20	0.299073	18.07994	0.00027*	0.999726
CLAST	20	0.275762	4.858207	0.003222	0.996778	UPL	20	0.404832	16.71438	0.000587	0.999413
MAL	22	0.326452	6.463575	0.002551	0.997449	UXMS	20	0.211082	1.970548	0.011474	0.988526
MRH	21	0.343365	5.550354	0.003827	0.996173	UIMS	20	0.190759	1.548838	0.015169	0.984831
MXRB	22	0.299528	3.629481	0.006811	0.993189	URN	20	0.275045	2.984833	0.008491	0.991509
MIRB	21	0.265374	2.7932	0.009026	0.990974	UOW	20	0.238712	2.573604	0.008603	0.991397
CVML	20	0.283088	10.33685	0.00075	0.99925	UCH	20	0.331738	3.396247	0.009541	0.990459
CVXMS	20	0.183409	1.652364	0.012321	0.987679	MC1L	20	0.076594	3.142691	0.000594	0.999406
CVIMS	20	0.155224	1.29824	0.014296	0.985704	MC2L	20	0.053645	4.371929	0.00015*	0.999849

Table 5.1: Continued.

Measurement	N	TEM	SD	P	R	Measurement	N	TEM	SD	P	R
CVWA	20	0.279374	3.722098	0.005634	0.994366	MC3L	20	0.061237	4.373725	0.0002*	0.999804
MC4L	20	0.133998	3.791994	0.001249	0.998751	FAPH	20	0.141559	3.823207	0.001371	0.998629
MC5L	20	0.163027	3.48723	0.002186	0.997814	FSIH	20	0.208806	4.076237	0.002624	0.997376
SZAB	22	0.334988	3.715727	0.008128	0.991872	FMLP	20	0.227791	7.753507	0.000863	0.999137
SZAW	22	0.167618	5.569261	0.000906	0.999094	TML	20	0.410284	23.98814	0.00029*	0.999707
SZAPA	22	0.413528	4.666154	0.007854	0.992146	TXNF	20	0.25399	3.506841	0.005246	0.994754
SZSIA	22	0.422899	5.399918	0.006133	0.993867	TINF	20	0.223408	2.566343	0.007578	0.992422
SZS1	22	0.257758	2.646021	0.009489	0.990511	TMLP	20	0.430762	5.433542	0.006285	0.993715
OCH	24	0.382487	13.76591	0.000772	0.999228	TMC	20	0.34444	3.71162	0.008612	0.991388
OCIB	22	0.369958	9.295295	0.001584	0.998416	TLC	20	0.297555	3.513688	0.007171	0.992829
OCPL	22	0.441674	5.005665	0.007785	0.992215	CZL	20	0.356682	5.543182	0.00414	0.99586
OCIS	24	0.444076	8.395412	0.002798	0.997202	CZB	20	0.363815	3.555919	0.010468	0.989532
OCAH	24	0.453045	3.901541	0.013484	0.986516	CZH	20	0.374351	3.6917	0.010283	0.989717
OCASH	24	0.411051	4.909249	0.007011	0.992989	TZL	20	0.385861	4.228297	0.008328	0.991672
OCASB	22	0.349046	5.684897	0.00377	0.99623	TZB	20	0.333333	3.236389	0.010608	0.989392
FML	20	0.350397	28.43253	0.00015*	0.999848	TZH	20	0.363624	2.497994	0.02119	0.97881
FXMS	20	0.27557	2.817976	0.009563	0.990437	MT1L	20	0.197512	4.067021	0.002358	0.997642
FIMS	20	0.225167	2.14355	0.011034	0.988966	MT2L	20	0.097382	4.651803	0.00044*	0.999562
FXST	20	0.355801	3.244254	0.012028	0.987972	MT3L	20	0.071297	4.465801	0.00026*	0.999745
FIST	20	0.364166	2.67506	0.018532	0.981468	MT4L	20	0.123716	4.723322	0.000686	0.999314
FEB	20	0.435252	5.826881	0.00558	0.99442	MT5L	20	0.092856	5.279206	0.00031*	0.999691
FLE	20	0.375648	4.618045	0.006617	0.993383						

$TEM= \sqrt{((\sum^{N}_{1} ((\sum^{K}_{1} M^2)- (\sum^{K}_{1} M^2/K))/N(K-1))}$

SD is standard deviation

$p= (TEM^2/SD^2)$

$R= 1- (TEM^2/SD^2)$

Table 5.2: Technical Error of Measurements (TEM) for the subadult population. (*p significant after a Bonferroni adjustment)

Measurement	N	TEM	SD	P	R	Measurement	N	TEM	SD	P	R
CFMTN	12	0.213698	2.542873	0.007062364	0.992938	HSMLP	14	0.075593	4.032526	0.00035*	0.999649
CMAH	14	0.138616	2.175899	0.004058324	0.995942	HGT	12	0.140238	4.072233	0.001186	0.998814
CMPL	12	0.231301	2.803079	0.006808997	0.993191	RML	11	0.190693	17.02399	0.00013*	0.999875
CMPB	12	0.167581	2.743592	0.003730866	0.996269	RXMS	11	0.123583	1.246904	0.009823	0.990177
CMSAST	12	0.183938	3.707844	0.002460945	0.997539	RIMS	11	0.10401	0.842716	0.015233	0.984767
CDGL	11	0.270017	2.666426	0.010254695	0.989745	RGH	9	0.090062	1.802635	0.002496	0.997504
COCL	10	0.20199	2.291664	0.007768876	0.992231	RSMLD	9	0.082999	2.186601	0.001441	0.998559
CECMIS	12	0.176068	2.107486	0.006979626	0.99302	RMLD	10	0.129228	2.673092	0.002337	0.997663
CFMTB	6	0.258199	7.135115	0.001309504	0.99869	UML	10	0.244949	18.87111	0.00017*	0.999832
MAL	10	0.224277	6.183156	0.001315672	0.998684	UPL	10	0.331662	18.37944	0.00037*	0.999674
MRH	10	0.257294	4.922651	0.002731869	0.997268	UXMS	10	0.110454	1.429413	0.005971	0.994029
MXRB	10	0.223159	3.213928	0.004821222	0.995179	UIMS	10	0.11	0.991938	0.012297	0.987703
MIRB	10	0.119164	2.453589	0.002358766	0.997641	URN	10	0.229347	3.065871	0.005596	0.994404
CVML	10	0.08	8.775782	8.31x10^{-05}*	0.999917	UOW	10	0.178045	2.093075	0.007236	0.992764
CVXMS	10	0.147648	1.176651	0.015745663	0.984254	UCH	10	0.120416	2.443163	0.002429	0.997571
CVIMS	10	0.093808	0.932583	0.010118302	0.989882	MC1L	10	0.134536	2.888738	0.002169	0.997831
CVWA	10	0.117473	2.233579	0.002766154	0.997234	MC2L	10	0.088318	3.879083	0.00052*	0.999482
CVWS	10	0.08124	1.949652	0.00173632	0.998264	MC3L	10	0.125698	3.991716	0.000992	0.999008
CVMC	10	0.180278	2.10392	0.007342175	0.992658	MC4L	10	0.105357	3.219599	0.001071	0.998929
CVLC	10	0.167033	2.095211	0.006355482	0.993645	MC5L	10	0.144568	3.054835	0.00224	0.99776
SGL	12	0.151658	2.899612	0.002735572	0.997264	SZAB	12	0.189077	2.622037	0.0052	0.9948
SGB	11	0.183402	2.054779	0.007966706	0.992033	SZS1	12	0.168325	2.588487	0.004229	0.995771
SAL	11	0.14554	3.858916	0.001422436	0.998578	OCH	12	0.199792	19.10017	0.00011*	0.999891
HML	14	0.169031	23.18797	5.314x10^{-05}*	0.999947	OCIB	10	0.266458	14.75336	0.00033*	0.999674
HXMS	14	0.142678	1.664845	0.007344621	0.992655	OCPL	11	0.260419	5.331545	0.002386	0.997614
HIMS	14	0.136539	1.345613	0.010296085	0.989704	OCIS	12	0.302214	8.496479	0.001265	0.998735
HDT	14	0.146629	1.764292	0.006907129	0.993093	OCASH	12	0.223607	3.940089	0.003221	0.996779
HSIH	13	0.27596	4.055328	0.004630628	0.995369	OCASB	11	0.202485	4.992331	0.001645	0.998355
HAPH	13	0.145708	3.976753	0.001342482	0.998658	FML	14	0.119523	33.04962	1.3x10^{-05}*	0.999987
HSMLD	12	0.104083	5.111446	0.00041464*	0.999585	FXMS	14	0.183225	2.14472	0.007298	0.992702

Table 5.2: Continued.

Measurement	N	TEM	SD	P	R	Measurement	N	TEM	SD	P	R
FIMS	14	0.13011	1.78644	0.00530449	0.994696	TMC	11	0.180151	4.533909	0.001579	0.998421
FXST	14	0.237397	2.743615	0.00748691	0.992513	TLC	12	0.263944	3.677947	0.00515	0.99485
FIST	14	0.230837	2.099844	0.012084721	0.987915	CZL	10	0.230868	6.220393	0.001378	0.998622
FSMLD	12	0.107626	5.725636	0.00035334*	0.999647	CZB	10	0.3245	4.107579	0.006241	0.993759
FEB	10	0.112694	7.614691	0.00021903*	0.999781	CZH	10	0.175214	4.394899	0.001589	0.998411
FLE	10	0.259615	5.707322	0.002069165	0.997931	TZL	12	0.136015	5.215914	0.0007*	0.99932
FAPH	12	0.088976	3.438818	0.00066946*	0.999331	TZB	12	0.28592	4.494439	0.004047	0.995953
FSIH	12	0.147761	3.540568	0.001741704	0.998258	TZH	12	0.191268	2.94271	0.004225	0.995775
FMLP	14	0.127055	6.479568	0.00038449*	0.999616	MT1L	12	0.163809	4.484443	0.001334	0.998666
TML	12	0.258199	26.48907	9.501×10^{-05}*	0.999905	MT2L	11	0.143019	4.455371	0.00103	0.99897
TXNF	12	0.206559	2.634005	0.006149725	0.99385	MT3L	11	0.160963	4.574243	0.001238	0.998762
TINF	12	0.15	2.194344	0.004672755	0.995327	MT4L	11	0.15667	4.635189	0.001142	0.998858
TSMLP	10	0.07	5.854434	0.00014296*	0.999857	MT5L	10	0.136015	4.954775	0.000754	0.999246
TMLP	12	0.144049	7.054231	0.00041698*	0.999583						

TEM= $\sqrt{((\sum^{N}_{1}((\sum^{K}_{1} M^{2})-(\sum^{K}_{1} M^{2}/K))/N(K-1))}$

SD is standard deviation

p= (TEM^{2}/SD^{2})

R= 1- (TEM^{2}/SD)

5.3.2 Intra-Observer Error: Measurement Error of Asymmetry

Results from two-way ANVOA tests indicate that, in all but two measurements, the between sides variation was significantly greater than the measurement error (ME), and thus further analysis was justified (see Tables 5.3-4). The two measurements which had greater ME than between side variance were both subadult measurements, CVIMS ($F=1.386$, $p=0.256$) and OCPL ($F=2.388$, $p=0.067$). As a result, these two measurements were removed from further analysis. The percentage of error within each remaining asymmetry score was between 0.05% and 17.8% for adults and between 0.03% and 27.24% for subadults (after CVIMS and OCPL were excluded). Repeatability was considerably lower for adult measurements FEB ($ME5=0.325$) and OCAH ($ME5=0.35$); however, both measurements showed significantly higher levels of between side variance to ME ($F=5.821$ $p=<0.0001$ and $F=1.532$ $p=<0.0001$, respectively), which indicates that these measurements still merited further analysis, although caution should be observed in any final interpretation of significance. Similarly, although results from the ANOVA indicate that the following subadult measurements warranted further analysis, there was considerably lower repeatability for TZH ($ME5=0.308$, $F=0.134$, $p=0.025$), OCIS ($ME5=0.368$, $F=0.411$, $p=0.007$), CZB ($ME5=0.46$, $F=0.557$, $p=0.002$), and UIMS ($ME5=0.466$, $F=0.065$, $p=0.002$). As with results from TEM, repeatability was high in both subadults and adults for most length measurements and many cranial measurements. The highest repeatability for adult measurements were found to be MC3L ($R=0.9947$), HML ($R=0.9939$), and MC2L ($R=0.9933$). Subadult repeatability was highest for FML ($R=0.9977$), CVMV ($R=0.9963$), and HML (0.9829).

Table 5.3: Measurement error of asymmetry: two-way ANOVA of sides by individual interaction for adults. (*p significant after a Bonferroni adjustment)

	Sides X Individuals				Error		%Error	Repeatability
Measurement	Df	MS	F	P	df	MS	ME3	ME5
COBB	10	6.196	79.435	<0.0001*	198	0.078	1.26	0.877
COBH	10	4.000	57.472	<0.0001*	198	0.070	1.74	0.837
CNOR	10	28.498	213.646	<0.0001*	198	0.133	0.47	0.9508
CFMTN	10	14.910	121.055	<0.0001*	198	0.123	0.83	0.9161
CFMTNS	9	16.8083	313.1016	<0.0001*	180	0.0537	0.32	0.969
CMAH	9	10.995	135.163	<0.0001*	180	0.081	0.74	0.9306
CMPL	9	23.655	191.779	<0.0001*	180	0.123	0.52	0.9502
CMPB	10	18.657	131.437	<0.0001*	198	0.142	0.76	0.9222
CMPH	9	6.7124	63.7821	<0.0001	180	0.1052	1.57	0.8626
CMSAST	9	20.6771	420.7411	<0.0001*	180	0.0491	0.24	0.9767
CDGL	10	27.676	162.328	<0.0001*	198	0.170	0.62	0.9362
COCL	9	28.9471	743.9286	<0.0001*	180	0.0389	0.13	0.9867
CECMIS	9	6.0727	76.1151	<0.0001*	180	0.0798	1.31	0.8825
COPO	10	20.487	131.722	<0.0001*	198	0.156	0.76	0.9224
CBAPO	10	9.508	74.155	<0.0001*	198	0.128	1.35	0.8693
CFMTB	10	31.315	185.083	<0.0001*	198	0.169	0.54	0.9436
CBPO	10	30.320	188.193	<0.0001*	198	0.161	0.53	0.9445
CBZO	10	8.354	46.202	<0.0001*	198	0.181	2.16	0.8043
CNMS	9	43.5361	330.6540	<0.0001*	180	0.1317	0.3	0.9706
CBAST	9	15.6356	151.3118	<0.0001*	180	0.1033	0.66	0.9376
CLFMT	9	43.8578	301.3130	<0.0001*	180	0.1456	0.33	0.9678
CLAST	9	45.2615	595.1975	<0.0001*	180	0.0760	0.17	0.9834
MAL	10	28.017	262.892	<0.0001*	198	0.107	0.38	0.9597
MRH	9	26.364	243.934	<0.0001*	180	0.108	0.41	0.9605
MXRB	10	20.638	230.029	<0.0001*	198	0.090	0.43	0.9542
MIRB	9	4.836	67.251	<0.0001*	180	0.072	1.49	0.8689
CVML	9	58.5513	730.6222	<0.0001*	180	0.0801	0.14	0.9865
CVXMS	9	1.5344	45.6134	<0.0001*	180	0.0336	2.19	0.8169
CVIMS	9	1.3497	56.0178	<0.0001*	180	0.0241	1.79	0.8462
CVWA	9	12.5681	161.0256	<0.0001*	180	0.0780	0.62	0.9412
CVWS	9	9.3349	256.3741	<0.0001*	180	0.0364	0.39	0.9623
CVMC	9	24.7137	122.8280	<0.0001*	180	0.2012	0.81	0.9241
CVLC	9	15.1019	140.3451	<0.0001*	180	0.1076	0.71	0.933
SGL	9	2.4003	15.8636	<0.0001*	180	0.1513	6.3	0.5978
SGB	9	4.669	105.9933	<0.0001*	180	0.044	0.94	0.913
SAL	9	21.7302	218.9192	<0.0001*	180	0.0993	0.46	0.9561
SCL	9	1.6404	28.7853	<0.0001*	180	0.0570	3.47	0.7353
HML	9	100.0472	1622.3874	<0.0001*	180	0.0617	0.06	0.9939
HXMS	9	2.172	31.2528	<0.0001*	180	0.069	3.2	0.7516
HIMS	9	2.1609	87.2890	<0.0001*	180	0.0248	1.15	0.8961
HDT	9	0.9467	11.1201	<0.0001*	180	0.0851	8.99	0.503
HSIH	9	3.7056	77.1652	<0.0001*	180	0.0480	1.3	0.8839
HAPH	9	2.6351	45.2110	<0.0001*	180	0.0583	2.21	0.8155
HEB	9	6.0201	652.3835	<0.0001*	180	0.0092	0.15	0.9849
HGT	9	2.1614	24.6613	<0.0001*	180	0.0876	4.05	0.7029
RML	9	21.9911	157.0794	<0.0001*	180	0.1400	0.64	0.9398
RXMS	9	1.8049	57.0875	<0.0001*	180	0.0316	1.75	0.8487
RIMS	9	0.9970	40.3462	<0.0001*	180	0.0247	2.48	0.7974
RGH	9	2.6479	80.2811	<0.0001*	180	0.0330	1.25	0.888
RMLD	9	1.7994	29.9959	<0.0001*	180	0.0600	3.33	0.7436

Table 5.3: Continued.

Measurement	Sides X Individuals Df	MS	F	P	Error df	MS	%Error ME3	Repeatability ME5
UML	9	41.1006	459.5093	<0.0001*	180	0.0894	0.22	0.9787
UPL	9	47.7606	291.4203	<0.0001*	180	0.1639	0.34	0.9667
UXMS	9	2.9518	66.2489	<0.0001*	180	0.0446	1.51	0.8671
UIMS	9	2.5781	70.8482	<0.0001*	180	0.0364	1.41	0.8748
URN	9	5.4731	72.3479	<0.0001*	180	0.0756	1.38	0.8771
UOW	9	9.0138	158.1832	<0.0001*	180	0.0570	0.63	0.9402
UCH	9	10.8979	99.0272	<0.0001*	180	0.1101	1.01	0.9074
MC1L	9	4.7730	813.5833	<0.0001*	180	0.0059	0.12	0.9878
MC2L	9	4.2528	1477.8069	<0.0001*	180	0.0029	0.07	0.9933
MC3L	9	7.0386	1876.9496	<0.0001*	180	0.0037	0.05	0.9947
MC4L	9	5.8650	326.6386	<0.0001*	180	0.0180	0.31	0.9702
MC5L	9	7.3937	278.1906	<0.0001*	180	0.0266	0.36	0.9652
SZAB	10	13.605	121.235	<0.0001*	198	0.112	0.82	0.9162
SZAW	10	26.268	934.928	<0.0001*	198	0.028	0.11	0.9884
SZAPA	10	25.383	148.436	<0.0001*	198	0.171	0.67	0.9306
SZSIA	10	52.702	294.685	<0.0001*	198	0.179	0.34	0.9639
SZS1	10	2.193	33.008	<0.0001*	198	0.066	3.03	0.7442
OCH	11	15.382	105.142	<0.0001*	216	0.146	0.95	0.8967
OCIB	9	37.080	254.748	<0.0001*	180	0.146	0.39	0.9621
OCPL	9	11.546	61.929	<0.0001*	180	0.186	1.61	0.859
OCIS	11	7.809	39.599	<0.0001*	216	0.197	2.53	0.7628
OCAH	11	1.532	7.464	<0.0001*	216	0.205	13.4	0.3501
OCASH	11	129.437	766.065	<0.0001*	216	0.169	0.13	0.9846
OCASB	9	8.508	69.528	<0.0001*	180	0.122	1.44	0.8727
FML	9	68.447	557.489	<0.0001*	180	0.123	0.18	0.9823
FXMS	9	11.005	144.923	<0.0001*	180	0.076	0.69	0.935
FIMS	9	2.970	58.579	<0.0001*	180	0.051	1.71	0.852
FXST	9	7.673	60.609	<0.0001*	180	0.127	1.65	0.8563
FIST	9	3.656	27.568	<0.0001*	180	0.133	3.63	0.7265
FEB	9	1.103	5.821	<0.0001*	180	0.189	17.18	0.3253
FLE	9	6.753	47.858	<0.0001*	180	0.141	2.09	0.8241
FAPH	9	1.326	66.194	<0.0001*	180	0.020	1.51	0.867
FSIH	9	4.312	98.909	<0.0001*	180	0.044	1.01	0.9073
FMLP	9	18.480	356.154	<0.0001*	180	0.052	0.28	0.9726
TML	9	54.256	322.314	<0.0001*	180	0.168	0.31	0.9698
TXNF	9	7.102	110.084	<0.0001*	180	0.065	0.91	0.916
TINF	9	2.563	51.345	<0.0001*	180	0.050	1.95	0.8343
TMLP	9	2.802	15.102	<0.0001*	180	0.186	6.62	0.5851
TMC	9	4.436	37.395	<0.0001*	180	0.119	2.67	0.7845
TLC	9	4.291	48.467	<0.0001*	180	0.089	2.06	0.826
CZL	9	8.758	68.843	<0.0001*	180	0.127	1.45	0.8715
CZB	9	4.596	34.721	<0.0001*	180	0.132	2.88	0.7713
CZH	9	5.473	39.057	<0.0001*	180	0.140	2.56	0.7919
TZL	9	5.144	34.55	<0.0001*	180	0.149	2.89	0.7704
TZB	9	1.313	11.820	<0.0001*	180	0.111	8.46	0.5197
TZH	9	2.424	18.336	<0.0001*	180	0.132	5.45	0.6342
MT1L	9	5.307	136.036	<0.0001*	180	0.039	0.74	0.9311
MT2L	9	6.967	734.634	<0.0001*	180	0.009	0.14	0.9866
MT3L	9	4.913	966.454	<0.0001*	180	0.005	0.1	0.9897
MT4L	9	3.780	246.978	<0.0001*	180	0.015	0.4	0.9609
MT5L	9	7.282	844.536	<0.0001*	180	0.009	0.12	0.9883

ME5= $\underline{MS_{interaction}-MS_m}/(MS_{interaction}+(n\text{-}1)MS_m$ and ME3=$MS_m/MS_{interaction}$ X 100

Table 5.4: Measurement error of asymmetry: two-way ANOVA of sides by individual interaction for subadults. (+measurement excluded from further analysis as p>0.05; *p significant after a Bonferroni adjustment).

	Sides X Individuals				Error		%Error	Repeatability
Measurement	df	MS	F	P	df	MS	ME3	ME5
CFMTN	5	1.145	25.077	<0.0001*	48	0.046	3.99	0.8005
CMAH	6	0.855	44.493	<0.0001*	56	0.019	2.25	0.8614
CMPL	5	1.530	28.601	<0.0001*	48	0.053	3.50	0.8214
CMPB	5	3.079	109.637	<0.0001*	48	0.028	0.91	0.9477
CMSAST	5	6.164	182.183	<0.0001*	48	0.034	0.55	0.9679
CDGL	4	2.707	36.333	<0.0001*	40	0.074	2.75	0.876
COCL	4	10.359	253.904	<0.0001*	40	0.041	0.39	0.9806
CECMIS	5	0.424	13.683	<0.0001*	48	0.031	7.31	0.6788
CFMTB	2	7.433	111.500	<0.0001*	24	0.067	0.90	0.9736
MAL	4	2.682	53.326	<0.0001*	40	0.050	1.88	0.9128
MRH	4	1.606	24.255	<0.0001*	40	0.066	4.12	0.823
MXRB	4	1.746	35.060	<0.0001*	40	0.050	2.85	0.872
MIRB	4	0.427	30.056	<0.0001*	40	0.014	3.33	0.8532
CVML	4	8.533	1333.250	<0.0001*	40	0.006	0.08	0.9963
CVXMS	4	0.294	13.477	<0.0001*	40	0.022	7.42	0.7139
CVIMS	4	0.012	1.386	0.2560+	40	0.009	72.13	0.0717
CVWA	4	2.027	146.862	<0.0001*	40	0.014	0.68	0.9669
CVWS	4	0.723	109.500	<0.0001*	40	0.007	0.91	0.9559
CVMC	4	5.819	179.055	<0.0001*	40	0.032	0.56	0.9727
CVLC	4	3.610	129.401	<0.0001*	40	0.028	0.77	0.9625
SGL	5	0.789	34.320	<0.0001*	48	0.023	2.91	0.8474
SGB	4	0.337	18.944	<0.0001*	40	0.018	5.28	0.7821
SAL	4	0.467	20.291	<0.0001*	40	0.023	4.93	0.7942
HML	6	11.557	404.500	<0.0001*	56	0.029	0.25	0.9829
HXMS	6	0.401	19.722	<0.0001*	56	0.020	5.07	0.7279
HIMS	6	0.233	12.493	<0.0001*	56	0.019	8.00	0.6215
HDT	6	0.790	36.757	<0.0001*	56	0.021	2.72	0.8363
HSIH	5	1.060	13.676	<0.0001*	48	0.077	7.31	0.6787
HAPH	5	0.637	28.198	<0.0001*	48	0.023	3.55	0.8193
HSMLD	4	0.573	55.115	<0.0001*	40	0.010	1.81	0.9154
HSMLP	6	0.409	71.617	<0.0001*	56	0.006	1.40	0.9098
HGT	4	2.290	116.234	<0.0001*	40	0.020	0.86	0.9584
RML	4	8.000	200.000	<0.0001*	40	0.040	0.50	0.9755
RXMS	4	0.258	17.793	<0.0001*	40	0.014	5.62	0.7706
RIMS	4	0.243	21.670	<0.0001*	40	0.011	4.61	0.8052
RGH	2	0.190	16.794	<0.0001*	24	0.011	5.95	0.8404
RSMLD	2	0.069	18.087	<0.0001*	24	0.004	5.53	0.8506
RMLD	4	0.274	16.425	<0.0001*	40	0.017	6.09	0.7552
UML	4	6.820	113.667	<0.0001*	40	0.060	0.88	0.9575
UPL	4	5.420	49.273	<0.0001*	40	0.110	2.03	0.9061
UXMS	4	0.628	51.500	<0.0001*	40	0.012	1.94	0.9099
UIMS	4	0.065	5.355	<0.01*	40	0.012	18.67	0.4655
URN	4	0.723	13.740	<0.0001*	40	0.053	7.28	0.7181
UOW	4	0.883	27.845	<0.0001*	40	0.032	3.59	0.843
UCH	4	0.986	68.021	<0.0001*	40	0.015	1.47	0.9306
MC1L	4	0.142	7.818	<0.0001*	40	0.018	12.79	0.5769
MC2L	4	0.335	42.910	<0.0001*	40	0.008	2.33	0.8934
MC3L	4	0.489	30.937	<0.0001*	40	0.016	3.23	0.8569
MC4L	4	0.333	29.955	<0.0001*	40	0.011	3.34	0.8527
MC5L	4	1.640	78.459	<0.0001*	40	0.021	1.27	0.9394

Table 5.4: Continued.

	Sides X Individuals				Error		%Error	Repeatability
Measurement	df	MS	F	P	df	MS	ME3	ME5
SZAB	5	4.478	125.256	<0.0001*	48	0.036	0.80	0.9539
SZS1	5	0.782	27.606	<0.0001*	48	0.028	3.62	0.816
OCH	5	5.707	142.965	<0.0001*	48	0.040	0.70	0.9594
OCIB	3	5.414	61.007	<0.0001*	32	0.089	1.64	0.9375
OCPL	4	0.169	2.388	0.06703+	40	0.071	41.88	0.2173
OCIS	5	0.411	4.501	<0.01*	48	0.091	22.22	0.3685
OCASH	5	7.813	156.267	<0.0001*	48	0.050	0.64	0.9628
OCASB	4	1.542	40.780	<0.0001*	40	0.038	2.45	0.8883
FML	6	43.848	3069.333	<0.0001*	56	0.014	0.03	0.9977
FXMS	6	1.009	30.052	<0.0001*	56	0.034	3.33	0.8058
FIMS	6	0.275	16.242	<0.0001*	56	0.017	6.16	0.6853
FXST	6	1.627	28.874	<0.0001*	56	0.056	3.46	0.7993
FIST	6	0.643	12.061	<0.0001*	56	0.053	8.29	0.6124
FSMLD	4	1.780	139.039	<0.0001*	40	0.013	0.72	0.965
FEB	3	0.129	10.118	<0.0001*	32	0.013	9.88	0.6951
FLE	3	0.455	5.870	<0.01*	32	0.078	17.04	0.549
FAPH	5	0.324	40.960	<0.0001*	48	0.008	2.44	0.8695
FSIH	5	1.131	51.811	<0.0001*	48	0.022	1.93	0.8944
FMLP	6	0.841	52.091	<0.0001*	56	0.016	1.92	0.8795
TML	5	8.840	132.600	<0.0001*	48	0.067	0.75	0.9564
TXNF	5	0.724	16.959	<0.0001*	48	0.043	5.90	0.7268
TINF	5	0.187	8.296	<0.0001*	48	0.022	12.05	0.5487
TSMLP	3	0.551	113.009	<0.0001*	32	0.005	0.88	0.9655
TMLP	5	1.979	95.364	<0.0001*	48	0.021	1.05	0.9402
TMC	4	0.972	27.777	<0.0001*	40	0.035	3.60	0.8427
TLC	5	1.197	17.176	<0.0001*	48	0.070	5.82	0.7294
CZL	4	1.112	20.863	<0.0001*	40	0.053	4.79	0.7989
CZB	4	0.557	5.292	<0.01*	40	0.105	18.89	0.4619
CZH	4	0.515	16.765	<0.0001*	40	0.031	5.96	0.7592
TZL	5	0.251	13.578	<0.0001*	48	0.018	7.36	0.677
TZB	5	0.621	7.592	<0.0001*	48	0.082	13.17	0.5235
TZH	5	0.134	3.671	<0.01*	48	0.037	27.24	0.308
MT1L	5	1.294	48.224	<0.0001*	48	0.027	2.07	0.8873
MT2L	4	1.786	79.369	<0.0001*	40	0.022	1.26	0.94
MT3L	4	1.580	61.467	<0.0001*	40	0.026	1.63	0.9236
MT4L	4	0.909	34.702	<0.0001*	40	0.026	2.88	0.8708
MT5L	4	4.264	230.497	<0.0001*	40	0.018	0.43	0.9787

ME5= $\underline{MS_{interaction}-MS_m}/(MS_{interaction}+(n-1)MS_m$ and ME3=$MS_m/MS_{interaction}$ X 100

5.3.3 Inter-Observer Error

Individual TEM tests for each observer indicate a high level of accuracy when taking unilateral measurements (see Tables AP 5.1-5 and the electronic appendix). Observers 1 and 4 had coefficients of reliability of 95-100%, and Observer 2 had an accuracy of 97-100% for all measurements taken. Observer 3 had the lowest repeatability for a single measurement at 94% for CVXMS. A comparison of measurements taken between the author and Observers 1-4 indicate that there was also a high reproducibility of results, 95-100% for all but four measurements. The coefficient of reliability was low for CNMS (R=0.319), CNOR (R=0.521), CFMTN (R=0.766), and MRH (R=0.851). This inter-observer error was later found to be due to Observer 1 measuring to *glabella* instead of *nasion,* and measuring *gonion* instead of the most inferior point on the ramus.

Although the TEM was found to have high accuracy, two-way ANOVA results for error in asymmetry show low reliability and repeatability for both observers individually and for inter-observer error, which was low for almost one half of the measurements (see Table AP 5.6-7 and the electronic Appendix). Pooled error for Observers 1-4 indicate that there were ten measurements that had unacceptable levels of ME, including CVIMS (F=0.611, p=0.7181) and TMLP (F=0.902, p=0.5297), TZL (F=1.154, p=0.3832), HDT (F=1.388, p=0.2764), OCAH (F=1.810, p=0.1087), CZB (F=1.633, p=0.2103), FAPH (F=1.812, p=0.1537), MC4L (F=1.732, p=0.1861), RMLD (F=2.457, p=0.778), and TINF (F=2.756, p=0.697). Repeatability (ME5) for these measurements was extremely low, being between -5.88% to 22.64% and ME3 was very high at 164.12% to 36.28%. Additionally, although they have acceptable levels of ME relative to asymmetry, there were a further 26 measurements that had a repeatability of below 50%. The remaining measurements had relatively low ME3, ranging from 0-11.3%, with a repeatability of 50-100%. Measurements that had the highest repeatability and lowest ME3 were most of the cranial traits and the element length measurements. Similarly in an inter-observer comparison between Observers 1-4 and the author, 13 measurements were found to have unacceptable levels of ME to asymmetry, including MRH (F=0.238, p=0.978), CNMS (F=0.439, p=0.898), CNOR (F=0.963, 0.493), HDT (F=1.225, p=0.346), RMLD

(F=1.432, p=0.271), TMLP (F=1.415, p=0.237), CFMTN (F=1.452, p=0.232), FEB (F=1.929, p=0.131), TZH (F=2.042, p=0.127), CVIMS (F=2.110, p=0.117), OCAH (F=1.835, p=0.103), FIST (F=2.315, p=0.078), and CVXMS (F=2.646, p=0.0.63). As with the TEM, the three cranial and one mandibular measurement that failed the inter-observer error test can be attributed to Observer 1 mistakenly taking the measurements from the wrong craniometric points. The remaining nine measurements had a low reproducibility, between 2.7% and 19.03%, and ME3 was high at 81.7% to 37.8%. Further, although they have acceptable levels of ME, a further 35 measurements had a repeatability score below 50%. The remaining measurements had relatively low ME3 of between 0 and 12.6%, with a repeatability of 50-94%. Those measurements that had the highest repeatability were the element length measurements and OCASH. Although many of these measurements exhibited high ME for inter-observer error, the low amount of ME found during intra-observer error tests indicate that all measurements warranted further analysis (see Section 6.11)

5.4 Normality and Antisymmetry

Forty-five of the adult and 14 of the subadult measurements tested significantly for departures from normality using a Kolmogorov-Smirnov test (see Tables 5.5-6). Many of the measurements—especially those of the calcaneus, talus, tibia, and cranium—remained non-normal when each sub-sample (i.e. age, sex, archeological site, settlement type, and period) was examined. Normality was not obtained even after all measurements were log transformed and adjusted for size using the DA1 formula (see electronic appendix). Kurtosis was also found to be significant in 33 subadult and 55 adult measurements. These traits all have a distribution that suggests leptokurtosis, which has been found to be present in most asymmetry studies. However, the causes of leptokurtosis have yet to be fully understood. Leptokurtosis could either be a result of a mixture of the type of asymmetry, different levels of asymmetry within a population or on an individual basis, or they could be indicative of underlying developmental stability and fluctuating asymmetry of the studied population (Palmer and Strobeck 1992; Leung and Forbes 1997; Møller and Swaddle 1997; Van Dongen 1998; Gangestad and Thornhill 1999; Palmer and Strobeck 2003). Although 11 adult and 15 subadult measurements had a degree of platykurtosis, none of these were found to be significant, suggesting that they do not have significant levels of anti-symmetry (Palmer and Strobeck 1992; Møller and Swaddle 1997; Palmer and Strobeck 2003). Additionally, skewness was found to be significant in 15 adult measurements, of which five were negative, and in 14 subadults, of which four were negative.

Many of these measurements were found to be normal when sub-samples were analyzed separately (see electronic appendix). For instance, it was found that all measurements were normally distributed through Kolmogorov-Smirnov testing for the Towton and Hickleton sample populations and for the age groups foetal to infant and early childhood (although some measurements were still significant for kurtosis and skew). This indicates that a likely explanation for non-normal distributions, indicative of leptokurtosis and skew, found in the pooled sample is a mixture of populations with differing levels of variance and asymmetry within each sub-sample.

Table 5.5: Normality tests for adult (R-L). (*Non-normal distribution; **p remains significant after a Bonferroni adjustment).

	Kolmogorov-Smirnov test			Kurtosis		Skew test	
Measurement	N	D	P	Kurtosis	P	Skew	P
COBB	223	0.0459	0.7359	0.3012	0.3533	-0.0068	0.9665
COBH	230	0.055	0.49	0.1149	0.7192	-0.1032	0.5203
CNOR	222	0.0564	0.4802	-0.2649	0.4154	0.0938	0.5658
CFMTN	598	0.0562	0.0455*	1.059	<0.0001**	-0.2402	0.0162*
CFMTNS	231	0.0778	0.1221	1.1278	0.0004**	-0.2923	0.0680
CMAH	637	0.0412	0.2297	0.6612	0.0006**	-0.0173	0.8583
CMPL	736	0.08	0.0002**	1.4045	<0.0001**	0.1642	0.0684
CMPB	806	0.0734	0.0003**	1.2619	<0.0001**	0.4191	<0.0001**
CMPH	695	0.035	0.362	0.4752	0.0103*	-0.0485	0.6009
CMSAST	691	0.0423	0.1692	-0.0208	0.9108	0.1178	0.2054
CDGL	762	0.0376	0.2307	0.3663	0.0384*	-0.1922	0.03*
COCL	538	0.0743	0.0053*	1.0081	<0.0001**	0.0923	0.3808
CECMIS	363	0.0802	0.0186*	1.3266	<0.0001**	-0.1361	0.2879
COPO	365	0.1038	0.0008*	1.3876	<0.0001**	-0.1621	0.2042
CBAPO	342	0.1007	0.002*	1.4102	<0.0001**	-0.069	0.6010
CFMTB	504	0.2708	<0.0001**	2.7048	<0.0001**	0.361	0.0009*
CBPO	386	0.1806	<0.0001**	1.6531	<0.0001**	0.5226	<0.0001**
CBZO	213	0.2544	<0.0001**	1.7956	<0.0001**	1.2403	<0.0001**
CNMS	325	0.2698	<0.0001**	2.3866	<0.0001**	0.3954	0.0035*
CBAST	474	0.1759	<0.0001**	1.205	<0.0001**	0.2067	0.0654
CLFMT	418	0.2403	<0.0001**	1.4908	<0.0001**	0.1944	0.1035
CLAST	478	0.0802	0.0043*	1.0451	<0.0001**	0.3263	0.0035*
MAL	528	0.0968	0.0001**	1.3694	<0.0001**	0.066	0.5348
MRH	529	0.0732	0.0069*	1.4888	<0.0001**	0.0078	0.9414
MXRB	389	0.0299	0.8779	0.2669	0.2795	0.1281	0.3006
MIRB	710	0.0454	0.1065	-0.0117	0.9493	0.0727	0.4280
CVML	485	0.0688	0.0203*	0.0372	0.8667	0.0383	0.7300
CVXMS	860	0.0436	0.076	0.3528	0.0342*	-0.015	0.8576
CVIMS	867	0.0406	0.1144	0.0738	0.6564	0.1226	0.1399
CVWA	550	0.0441	0.2344	0.4218	0.0426*	0.0599	0.5654
CVWS	507	0.0482	0.1886	0.4999	0.021*	0.0194	0.8583
CVMC	465	0.0295	0.8118	0.0567	0.8019	0.0339	0.7649
CVLC	452	0.039	0.4966	-0.16	0.4852	-0.0617	0.5909
SGL	505	0.0394	0.4121	0.5129	0.0181*	0.0271	0.8032
SGB	511	0.0465	0.2186	0.3477	0.107	-0.2074	0.0550
SAL	227	0.1071	0.011*	1.3433	<0.0001**	-0.0541	0.7378
SCL	216	0.0432	0.8149	0.1152	0.7266	-0.0277	0.8673
HML	552	0.0646	0.0199*	0.1932	0.3521	-0.0613	0.5555
HXMS	895	0.0503	0.0217*	0.429	0.0086*	0.1009	0.2173
HIMS	890	0.0523	0.0155*	0.1012	0.5366	-0.0609	0.4574
HDT	875	0.0389	0.1413	0.681	<0.0001**	-0.156	0.0591
HSIH	633	0.0306	0.5929	0.2251	0.2459	0.0423	0.6635
HAPH	526	0.0516	0.1214	0.2488	0.2419	0.0574	0.5900
HEB	674	0.0315	0.5175	-0.0431	0.8189	0.0711	0.4500
HGT	484	0.0402	0.4154	-0.0179	0.9356	0.1695	0.1268
RML	466	0.0812	0.0043*	0.4645	0.0396*	-0.1789	0.1137
RXMS	850	0.0456	0.0586	0.2115	0.2069	0.2139	0.0108*
RIMS	853	0.0566	0.0084*	0.2295	0.17	-0.0786	0.3479
RGH	356	0.0594	0.1617	0.6401	0.0131*	-0.0117	0.9276
RMLD	599	0.0444	0.1876	0.5002	0.0121*	0.1243	0.2131
UML	364	0.0776	0.0251*	0.1797	0.481	-0.0437	0.7324

Table 5.5: Continued.

Measurement	Kolmogorov-Smirnov test			Kurtosis		Skew test	
	N	D	P	Kurtosis	P	Skew	P
UPL	470	0.0668	0.0303*	0.4976	0.0269*	0.0145	0.8979
UXMS	800	0.041	0.1356	0.1813	0.2937	-0.137	0.1131
UIMS	812	0.047	0.0553	0.2835	0.0981	0.1719	0.0452*
URN	749	0.0363	0.2786	0.5984	0.0008*	-0.035	0.6950
UOW	697	0.0417	0.1774	0.3068	0.0971	-0.1032	0.2651
UCH	540	0.0382	0.4105	0.5451	0.0094*	0.076	0.4698
MC1L	524	0.0566	0.0697	0.1779	0.4035	-0.1401	0.1892
MC2L	541	0.0427	0.278	-0.2924	0.1632	-0.0034	0.9744
MC3L	524	0.0354	0.5283	-0.0721	0.735	-0.049	0.6459
MC4L	502	0.0424	0.3265	-0.0131	0.9521	0.1664	0.1268
MC5L	445	0.0412	0.4362	-0.0671	0.7715	-0.1215	0.2940
SZAB	548	0.0383	0.3963	0.7939	0.0001**	-0.081	0.4378
SZAW	386	0.0575	0.1556	0.4621	0.0622	0.0791	0.5241
SZAPA	454	0.042	0.4002	0.3181	0.1642	-0.2	0.0809
SZSIA	372	0.0542	0.224	0.9176	0.0003**	-0.2081	0.1000
SZS1	648	0.0593	0.0209*	0.3669	0.0557	-0.198	0.0392*
OCH	275	0.1643	<0.0001**	0.8249	0.0049*	-0.4137	0.0049*
OCIB	186	0.106	0.0306*	0.2154	0.5436	-0.1644	0.3562
OCPL	166	0.0453	0.8849	-0.0893	0.8117	-0.0743	0.6935
OCIS	421	0.0555	0.1497	0.5539	0.0196*	0.1223	0.3039
OCAH	694	0.0613	0.0109*	0.5683	0.0022*	0.0323	0.7275
OCASH	811	0.0425	0.1062	0.7138	<0.0001**	0.032	0.7091
OCASB	489	0.0699	0.0168*	1.8569	<0.0001**	-0.0682	0.5366
FML	695	0.0608	0.0117*	0.1398	0.4503	-0.0762	0.4110
FXMS	933	0.038	0.1342	0.3012	0.0598	-0.0129	0.8721
FIMS	931	0.0552	0.0069*	0.878	<0.0001**	-0.0864	0.2809
FXST	948	0.0387	0.1162	0.6499	<0.0001**	0.0543	0.4945
FIST	959	0.0387	0.1126	0.5494	0.0005**	0.0131	0.8681
FEB	624	0.1885	<0.0001**	2.6729	<0.0001**	0.3444	0.0004**
FLE	622	0.1752	<0.0001**	0.6481	0.0009*	0.1747	0.0747
FAPH	866	0.051	0.0222*	0.7431	<0.0001**	0.0016	0.9848
FSIH	894	0.0416	0.0905	0.1954	0.2318	0.0272	0.7396
FMLP	747	0.0796	0.0002**	0.3255	0.0684	-0.1482	0.0976
TML	576	0.0805	0.0011*	0.3271	0.1076	0.0372	0.7148
TXNF	814	0.0339	0.3068	0.2121	0.2153	-0.079	0.3564
TINF	834	0.0495	0.0334*	0.5086	0.0026*	0.273	0.0013*
TMLP	488	0.2071	<0.0001**	0.6367	0.0039*	0.0975	0.3779
TMC	318	0.0724	0.0715	0.3002	0.2708	-0.0085	0.9502
TLC	324	0.0456	0.5106	0.3852	0.1539	0.0607	0.6541
CZL	661	0.2231	<0.0001**	1.304	<0.0001**	-0.0127	0.8936
CZB	599	0.2444	<0.0001**	1.3477	<0.0001**	-0.4092	<0.0001**
CZH	691	0.1789	<0.0001**	0.3645	0.0497*	0.0089	0.9235
TZL	630	0.2086	<0.0001**	1.3052	<0.0001**	0.0079	0.9353
TZB	646	0.2031	<0.0001**	0.6697	0.0005**	-0.0611	0.5253
TZH	660	0.2516	<0.0001**	0.2019	0.2878	-0.1614	0.0897
MT1L	556	0.0551	0.068	0.649	0.0017*	-0.1785	0.0850
MT2L	347	0.04	0.6346	0.0559	0.8305	-0.0963	0.4621
MT3L	364	0.0581	0.1716	0.1915	0.4528	0.1975	0.1225
MT4L	356	0.0415	0.5711	0.5329	0.0388*	0.074	0.5671
MT5L	378	0.041	0.5502	0.2413	0.3352	0.0432	0.7309

Table 5.6: Normality tests for subadult (R-L). (*Non-normal distribution; **p remains significant after a Bonferroni adjustment).

	Kolmogorov-Smirnov			Kurtosis		Skew	
Measurement	N	D	P	Skew	P	Skew	P
CFMTN	115	0.1142	0.0997	-0.0947	0.8323	0.3788	0.093
CMAH	141	0.065	0.5914	0.1535	0.7051	-0.0965	0.6366
CMPL	174	0.1187	0.0148*	1.4261	0.0001**	0.5482	0.0029*
CMPB	174	0.0947	0.0881	0.5337	0.1451	0.2105	0.2529
CMSAST	132	0.0503	0.8919	0.783	0.0615	0.1347	0.5228
CDGL	136	0.0594	0.724	0.3951	0.3384	-0.1022	0.6228
COCL	168	0.1013	0.0638	0.8487	0.0227*	0.3006	0.1086
CECMIS	120	0.098	0.1993	-0.4874	0.2662	0.1699	0.4417
CFMTB	45	0.1923	0.0717	0.1146	0.869	0.3791	0.2838
MAL	163	0.0852	0.1878	0.821	0.0299*	0.0598	0.753
MRH	176	0.056	0.6402	0.2978	0.4135	-0.058	0.7514
MXRB	144	0.1101	0.0611	1.0015	0.0126*	0.2094	0.3001
MIRB	217	0.0519	0.6018	0.5937	0.0711	0.0539	0.7442
CVML	144	0.0793	0.3254	1.8888	<0.0001**	-0.1878	0.3527
CVXMS	279	0.067	0.1634	0.4227	0.146	0.0558	0.7019
CVIMS	276	0.082	0.0488	0.2731	0.35	0.267	0.0687
CVWA	159	0.0608	0.6002	0.9082	0.0176*	-0.1586	0.41
CVWS	156	0.1211	0.0206*	0.9939	0.0101*	0.5655	0.0036*
CVMC	70	0.0937	0.5701	1.4803	0.009*	-0.1924	0.5023
CVLC	64	0.0558	0.9884	-0.3375	0.5677	-0.1907	0.524
SGL	188	0.0691	0.331	0.0021	0.9952	0.2328	0.1891
SGB	190	0.0651	0.3963	0.8381	0.0169*	-0.0703	0.6899
SAL	75	0.108	0.3455	1.6812	0.0022*	0.3968	0.1526
HML	195	0.1512	0.0003**	0.469	0.1759	0.5425	0.0018*
HXMS	300	0.0694	0.1107	0.4274	0.1276	0.297	0.0348*
HIMS	299	0.0733	0.0805	0.4568	0.104	0.0866	0.539
HDT	250	0.0738	0.1311	0.7382	0.0162*	-0.0013	0.9935
HSIH	79	0.0674	0.8652	0.188	0.7253	0.0882	0.7444
HAPH	72	0.133	0.1566	0.9122	0.1026	-0.2087	0.4607
HSMLD	157	0.0661	0.4989	0.6906	0.0729	0.1692	0.3822
HSMLP	156	0.076	0.3281	0.1378	0.7213	0.4469	0.0214*
HGT	42	0.1136	0.6506	-0.2598	0.717	0.5278	0.1486
RML	125	0.119	0.0581	0.6247	0.1462	0.6649	0.0021*
RXMS	273	0.0853	0.0376*	0.1662	0.5717	0.3911	0.008*
RIMS	269	0.0716	0.1273	0.5077	0.0863	0.015	0.9194
RGH	118	0.1129	0.0988	0.404	0.3606	-0.069	0.7565
RSMLD	85	0.1248	0.1415	0.0655	0.8992	0.413	0.1138
RMLD	33	0.0759	0.9913	-0.1685	0.8328	0.0744	0.8555
UML	110	0.1464	0.0179*	0.7696	0.0922	-0.0303	0.8952
UPL	105	0.1048	0.1989	0.3181	0.4961	-0.1233	0.601
UXMS	261	0.0776	0.0864	0.7993	0.0078*	0.143	0.3428
UIMS	267	0.0787	0.073	0.2895	0.3299	0.2324	0.119
URN	215	0.0803	0.1245	0.4653	0.1589	0.1878	0.2578
UOW	220	0.0554	0.5095	0.9462	0.0038*	0.0625	0.703
UCH	200	0.0965	0.0482*	1.3305	<0.0001**	0.8126	<0.0001**
MC1L	60	0.0869	0.7556	0.2813	0.6438	-0.3855	0.2117
MC2L	77	0.1179	0.2348	-0.385	0.4771	0.2452	0.3707
MC3L	74	0.0668	0.8965	-0.4117	0.4556	0.1546	0.5799
MC4L	70	0.0778	0.791	0.3505	0.536	-0.2386	0.4054
MC5L	48	0.0589	0.9963	-0.1178	0.8613	0.0827	0.8095

Table 5.6: Continued.

Measurement	Kolmogorov-Smirnov N	D	P	Kurtosis Skew	P	Skew Skew	P
SZAB	140	0.0594	0.7061	0.6839	0.0929	-0.0269	0.8954
SZS1	157	0.0969	0.1049	-0.3712	0.335	0.2155	0.2658
OCH	158	0.1459	0.0024*	1.2404	0.0012*	-0.4952	0.0103*
OCIB	115	0.1323	0.0356	1.5896	0.0004**	0.2773	0.2188
OCPL	115	0.0813	0.4325	0.8612	0.0543	0.1004	0.656
OCIS	180	0.0827	0.1701	0.8583	0.0172*	0.2528	0.1627
OCASH	306	0.0691	0.1079	0.802	0.0039*	-0.0544	0.6961
OCASB	211	0.0673	0.2951	0.6796	0.0415*	0.2771	0.098
FML	198	0.1475	0.0004**	1.5549	<0.0001**	-0.6014	0.0005**
FXMS	295	0.0883	0.0202*	1.0135	0.0003**	-0.1186	0.4033
FIMS	299	0.1069	0.0022*	0.7546	0.0073*	-0.373	0.0081*
FXST	312	0.0697	0.0968	1.2905	<0.0001**	-0.2556	0.064
FIST	316	0.0565	0.2657	1.0951	<0.0001**	0.098	0.4749
FSMLD	110	0.059	0.839	0.7155	0.1175	-0.0368	0.873
FEB	75	0.1422	0.0963	-0.1531	0.7801	0.4531	0.1024
FLE	122	0.1214	0.0549	0.9672	0.0262*	-0.5571	0.011*
FAPH	162	0.0945	0.1105	1.4149	0.0002**	0.0339	0.859
FSIH	153	0.0744	0.365	0.3073	0.4305	0.0169	0.9312
FMLP	255	0.0699	0.1654	0.9178	0.0025*	-0.1959	0.199
TML	174	0.1286	0.0063*	1.156	0.0016*	0.322	0.0804
TXNF	276	0.0719	0.1153	1.4825	<0.0001**	0.3081	0.0357*
TINF	275	0.0766	0.0796	0.8189	0.0052*	0.2805	0.0563
TSMLP	87	0.0758	0.7001	1.8067	0.0004**	0.4948	0.0554
TMLP	89	0.0899	0.4683	-0.4716	0.351	-0.4087	0.1096
TMC	52	0.0921	0.7699	1.2889	0.0474*	-0.5131	0.1204
TLC	55	0.1149	0.4626	0.758	0.2315	-0.2174	0.4992
CZL	122	0.1582	0.0045*	0.7097	0.1027	0.0153	0.9442
CZB	102	0.105	0.2106	0.298	0.5294	-0.3297	0.1679
CZH	104	0.1403	0.0332*	0.2189	0.641	0.6365	0.0072*
TZL	108	0.1305	0.0505	1.2391	0.0072*	-0.3827	0.0998
TZB	99	0.119	0.1212	-0.1391	0.7723	0.2074	0.3926
TZH	108	0.1417	0.0261*	0.4684	0.3097	0.4192	0.0714
MT1L	111	0.075	0.5596	0.4	0.3794	-0.1226	0.5932
MT2L	69	0.0793	0.7786	0.3679	0.5187	0.2276	0.4305
MT3L	62	0.068	0.9365	-0.2125	0.7229	-0.0241	0.9367
MT4L	59	0.0888	0.741	-0.0184	0.9761	0.2565	0.4098
MT5L	56	0.0678	0.9589	-0.2689	0.6687	-0.0347	0.9133

5.5 Directional asymmetry

5.5.1 Descriptive Statistics

The average median directional asymmetry for all adult measurements was found to be 0.36%, with a 95% confidence interval of between -5.79 to 6.62% ($\bar{x}$ =0.41% and σ =3.1%) (see Table 5.7). When the extent of the directionality of a measurement is taken into account (i.e. based on the median) there were a total of 16 measurements with medians favouring the left side, 56 measurements favouring the right side, and 29 measurements with an average median at zero. Analysis of indices of specific elements/joints indicates that only the cranium, mandible and tarsals are left-sided, while the remaining elements favour the right side (see Figure 5.1). Moreover, singular measurements in the upper limbs and hands, excluding the clavicle (which had left-side dominant traits for CVML, CVIMS, CVMC), were found to be all right-side dominant. However, measurements in the lower limbs, pelvic girdle and cranium were found to have a mixture of dominance and symmetry. The cranium had 11 measurements favouring symmetry and only three cranial base measurements left-side dominant, with the remaining eight measurements being right-side dominant. The sacrum was left dominant for the alae, but right dominant for the auricular surface. The *os coxae* was found to favour symmetry in length and breadth, and right-side dominant for all other measurements, except for the pubic symphysis length, which favoured the left side. The femur was left-side dominant in length and in midshaft measurements, but favouring symmetry in all other measurements except the femoral head, which was right-side dominant. Similarly, the tibia and tarsals favoured symmetry over dominance in most measurements, except for tibial diaphyseal measurements, which were of mixed asymmetry and symmetry. For the metatarsal lengths, MT1 was found to be left dominant and MT3 symmetrical, while the remaining metatarsal lengths were right-side dominant.

The measurements with the highest median DA favouring the left side were CVMC (-1.57%), CVML (-1.31%), and CVIMS (-0.91%). The highest levels of DA in a measurement favouring the right were RXMS (2.72%), HXMS (2.35%), and HDT (2.15%). The majority of those measurements that had an average median of zero could be found in the talus, calcaneus, cranium, femur, and tibia. For element indices, only five were found to be weakly left-sided dominant including the tarsals (-0.14%), lower long bone lengths (-0.13%), cranial base (-0.12%), mandible (-0.08%), and cranium (-0.06%). The remaining indices were found to be right-sided dominant, with those having the highest medians being upper limb midshafts (2.14%), humerus (1.51%), and shoulder (1.5%). Those measurements with the highest standard deviation, and thus the greatest range in DA levels, were CMPH (15.41%), CVLC (12.29%), and CDGL (13.29%). Measurements exhibiting the lowest standard deviation include OCH (0.68%), TML (0.87%), and FML and CLFMT (0.9%). Indices with the highest standard deviation include the temporal region of the cranium (4.57%), sacro-iliac joint (3.59%), and clavicle (3.09%). Those indices with the lowest standard deviation include lower long bone lengths (0.68%), lower limbs (0.78%), and metatarsals (0.79%).

When dominance was evaluated by the prevalence of individuals favouring one side over the other, without regard to the extent of the directionality, 22 measurements were found to favour the left side, 69 the right, and 10 favoured symmetry (see Table 5.7). A closer examination of these numbers indicates that the upper limbs were more right-side dominant than the lower limb and cranium, which were a mixture of dominance. The cranium was found to have 13 measurements that favoured the right side, six the left, and three of equal dominance; the mandible with two favouring the right side and two the left; the clavicle with four measurements right-side dominant and three left-sided; the scapula, humerus, radius, ulna and metacarpals had all measurements favouring the right; the sacrum having three right-side dominant and two favouring the left; the *os coxae* with five favouring the right side and two the left; the femur with six right-side dominant, and four left-sided; the tibia with three favouring the right side, two the left, and with one with equal dominance; all the tarsals favouring the right; and the metatarsals with four favouring the right and one the left. Those measurements that had less than a 10% difference in the number of individuals favouring one side over the over (excluding symmetrical individuals), and thus largely symmetrical, included COBH, CNOR, CFMTNS, CMAH, CMPH, COCL, COPO, MXRB, CVLC, SZAB, SZS1, FIMS, FIST, FMLP, TMC, CZL, TZB, and MT3L. Highly directional measurements included 14 traits that had over a 50% difference in the percentage of individuals favouring the right side over the left, and vice versa, including those to the right: CFMTB, CBZO, HML, HXMS, HDT, HAPH, HEB, HGT, RML, RXMS, UML, UPL, and FEB; with one to the left, CVML.

Table 5.7: Results for directional asymmetry in adults.

Measurement	N	Median	Mean	% of Individuals			Minimum	Maximum	Std. Dev.	Confidence interval of 95%
				L>R	R>L	R=L				
COBB	223	0.0054	0.0053	35.4	57.8	6.7	-0.0498	0.0525	0.0176	-2.99 to 4.05%
COBH	230	0.0000	-0.0010	47.8	48.3	3.9	-0.0638	0.0627	0.0222	-4.54 to 4.34%
CNOR	222	0.0000	0.0003	46.8	45.9	7.2	-0.0295	0.0347	0.0130	-2.57 to 2.63%
CFMTN	598	0.0036	0.0026	36.5	57.9	5.7	-0.0414	0.0407	0.0125	-2.24 to 2.76%
CFMTNS	231	0.0013	0.0000	46.3	50.6	3	-0.0614	0.0446	0.0152	-3.04 to 3.04%
CMAH	637	0.0000	0.0006	47.4	46.8	5.8	-0.1178	0.1252	0.0382	-7.58 to 7.7%
CECMIS	363	0.0030	0.0011	43.3	51	5.8	-0.0977	0.0934	0.0292	-5.73 to 5.95%
CFMTB	504	0.0000	0.0033	15.5	32.5	52	-0.0449	0.0509	0.0135	-2.37 to 3.03%
CBZO	213	0.0000	0.0061	6.1	47.4	46.5	-0.0225	0.0383	0.0099	-1.37 to 2.59%
CMPL	736	0.0067	0.0081	38	58	3.9	-0.1218	0.1362	0.0391	-7.01 to 8.63%
CMPB	806	0.0042	0.0064	41.3	53.5	5.2	-0.1169	0.1244	0.0358	-6.52 to 7.8%
CMPH	695	0.0000	0.0010	48.3	49.5	2.2	-0.5108	0.5070	0.1541	-30.72 to 30.92%
CMSAST	691	0.0069	0.0070	41.8	56.3	1.9	-0.0930	0.1100	0.0366	-6.62 to 8.02%
CDGL	762	-0.0068	-0.0096	52.6	46.3	1	-0.3330	0.3263	0.1021	-21.38 to 19.46%
COCL	538	0.0000	0.0001	48.5	47	4.5	-0.1803	0.1674	0.0551	-11.01 to 11.03%
COPO	365	-0.0013	-0.0016	50.4	46.8	2.7	-0.0649	0.0612	0.0203	-4.22 to 3.9%
CBAPO	342	-0.0045	-0.0039	58.8	38.6	2.6	-0.0822	0.0775	0.0247	-5.33 to 4.55%
CNMS	325	0.0000	0.0024	18.2	31.4	50.5	-0.0415	0.0392	0.0113	-2.02 to 2.5%
CBPO	386	0.0000	0.0044	24.9	42.7	32.4	-0.0576	0.0591	0.0164	-2.84 to 3.72%
CBAST	474	0.0000	0.0046	22.8	44.5	32.7	-0.0438	0.0513	0.0147	-2.48 to 3.4%
CLFMT	418	0.0000	0.0022	19.4	35.6	45	-0.0317	0.0306	0.0090	-1.58 to 2.02%
CLAST	478	0.0022	0.0040	43.7	53.8	2.5	-0.0615	0.0695	0.0217	-3.94 to 4.74%
MAL	528	-0.0017	-0.0015	54.7	40.9	4.4	-0.0442	0.0430	0.0132	-2.79 to 2.49%
MRH	529	0.0030	0.0033	40.6	55.8	3.6	-0.0690	0.0693	0.0204	-3.75 to 4.41%
MXRB	389	0.0023	0.0025	46.3	51.4	2.3	-0.1039	0.1102	0.0348	-6.71 to 7.21%
MIRB	710	-0.0069	-0.0064	56.6	40.8	2.5	-0.1082	0.1057	0.0364	-7.92 to 6.64%
CVML	484	-0.0131	-0.0116	62.2	24.8	13	-0.0785	0.0583	0.0230	-5.76 to 3.44%

Table 5.7: Continued.

Measurement	N	Median	Mean	% of Individuals			Minimum	Maximum	Std. Dev.	Confidence interval of 95%
				L>R	R>L	R=L				
CVXMS	860	0.0152	0.0136	36.7	57.3	5.9	-0.1737	0.1907	0.0593	-10.5 to 13.22%
CVIMS	867	-0.0091	-0.0060	51.6	43.6	4.8	-0.2208	0.2183	0.0748	-15.56 to 14.36%
CVWA	550	0.0130	0.0144	39.5	58.2	2.4	-0.1839	0.2124	0.0673	-12.02 to 14.9%
CVWS	507	0.0159	0.0167	37.7	59	3.4	-0.1463	0.1740	0.0551	-9.35 to 12.69%
CVMC	465	-0.0157	-0.0153	55.7	41.7	2.6	-0.2461	0.2683	0.0902	-19.57 to 16.51%
CVLC	452	0.0065	0.0091	47.8	50.4	1.8	-0.4112	0.3579	0.1329	-25.67 to 27.49%
SGL	505	0.0084	0.0089	33.7	62.8	3.6	-0.0633	0.0756	0.0238	-3.87 to 5.65%
SGB	511	0.0038	0.0046	40.9	53.8	5.3	-0.1001	0.0891	0.0312	-5.78 to 6.7%
SAL	227	0.0096	0.0144	33.9	61.7	4.4	-0.1344	0.1390	0.0410	-6.76 to 9.64%
SCL	216	0.0073	0.0084	38.4	59.7	1.9	-0.0675	0.0741	0.0256	-4.28 to 5.96%
HML	552	0.0101	0.0104	13	78.1	8.9	-0.0273	0.0440	0.0113	-1.22 to 3.3%
HXMS	895	0.0235	0.0239	23.9	72.3	3.8	-0.0980	0.1421	0.0372	-5.05 to 9.83%
HIMS	890	0.0169	0.0153	31.5	62.2	6.3	-0.1142	0.1224	0.0381	-6.09 to 9.15%
HDT	875	0.0215	0.0207	26.2	69.8	4	-0.1121	0.1324	0.0387	-5.67 to 9.81%
HSIH	633	0.0073	0.0076	35.1	61.3	3.6	-0.0634	0.0749	0.0224	-3.72 to 5.24%
HAPH	526	0.0139	0.0142	25.1	71.5	3.4	-0.0701	0.0859	0.0240	-3.38 to 6.22%
HEB	674	0.0090	0.0095	29.7	66.5	3.9	-0.0490	0.0665	0.0189	-2.83 to 4.73%
HGT	484	0.0179	0.0192	24	72.5	3.5	-0.0720	0.0992	0.0281	-3.7 to 7.54%
RML	466	0.0067	0.0066	20.2	64.4	15.5	-0.0384	0.0367	0.0114	-1.62 to 2.94%
RXMS	850	0.0272	0.0288	26	69.6	4.4	-0.1278	0.1846	0.0501	-7.14 to 12.9%
RIMS	853	0.0101	0.0103	36	56	8	-0.1407	0.1593	0.0480	-8.57 to 10.63%
RGH	356	0.0047	0.0056	37.6	55.6	6.7	-0.0794	0.0776	0.0255	-4.54 to 5.66%
RMLD	599	0.0067	0.0081	35.1	60.6	4.3	-0.0734	0.0815	0.0242	-4.03 to 5.65%
UML	364	0.0071	0.0069	22.3	67	10.7	-0.0283	0.0418	0.0118	-1.67 to 3.05%
UPL	470	0.0080	0.0076	22.8	64.5	12.8	-0.0401	0.0488	0.0135	-1.94 to 3.46%
UXMS	800	0.0191	0.0200	32.1	63.8	4.1	-0.1741	0.1699	0.0543	-8.86 to 12.86%
UIMS	812	0.0211	0.0236	33.9	60.8	5.3	-0.1401	0.2052	0.0639	-10.42 to 15.14%

Table 5.7: Continued.

Measurement	N	Median	Mean	% of Individuals			Minimum	Maximum	Std. Dev.	Confidence interval of 95%
				L>R	R>L	R=L				
URN	749	0.0085	0.0092	35.9	61.7	2.4	-0.0946	0.0895	0.0279	-4.66 to 6.5%
UOW	697	0.0082	0.0080	39.5	56.1	4.4	-0.0989	0.1070	0.0356	-6.32 to 7.92%
UCH	540	0.0077	0.0079	39.3	57.8	3	-0.0958	0.1038	0.0317	-5.55 to 7.13%
MC1L	524	0.0046	0.0051	35.9	59.9	4.2	-0.0506	0.0528	0.0159	-2.67 to 3.69%
MC2L	541	0.0029	0.0030	37.3	56.9	5.7	-0.0305	0.0363	0.0120	-2.1 to 2.7%
MC3L	524	0.0022	0.0024	41.6	54.4	4	-0.0424	0.0417	0.0147	-2.7 to 3.18%
MC4L	502	0.0035	0.0035	38.4	55.6	6	-0.0426	0.0480	0.0150	-2.65 to 3.35%
MC5L	445	0.0037	0.0036	40.2	55.3	4.5	-0.0483	0.0524	0.0180	-3.24 to 3.96%
SZAB	548	-0.0033	-0.0048	50.7	45.8	3.5	-0.2323	0.2107	0.0726	-15 to 14.04%
SZAW	386	-0.0037	-0.0017	53.1	45.3	1.6	-0.1176	0.1227	0.0406	-8.29 to 7.95%
SZAPA	454	0.0097	0.0090	41.4	56.6	2	-0.1963	0.1681	0.0613	-11.36 to 13.16%
SZSIA	372	0.0061	0.0035	41.1	57.3	1.6	-0.1126	0.1160	0.0378	-7.21 to 7.91%
SZS1	648	0.0000	-0.0023	46.8	49.2	4	-0.1431	0.1229	0.0441	-9.05 to 8.59%
OCH	275	0.0000	-0.0019	43.3	28.4	28.4	-0.0256	0.0220	0.0078	-1.75 to 1.37%
OCIB	186	0.0000	0.0000	40.3	45.2	14.5	-0.0397	0.0351	0.0133	-2.66 to 2.66%
OCPL	166	-0.0013	-0.0011	51.8	46.4	1.8	-0.0475	0.0387	0.0169	-3.49 to 3.27%
OCIS	421	0.0016	0.0016	45.4	52.5	2.1	-0.0310	0.0324	0.0102	-1.88 to 2.2%
OCAH	694	0.0037	0.0039	38.9	57.3	3.7	-0.0614	0.0622	0.0188	-3.37 to 4.15%
OCASH	811	0.0072	0.0076	43.8	54.4	1.8	-0.1986	0.2102	0.0608	-11.4 to 12.92%
OCASB	489	0.0038	0.0046	42.9	54.6	2.5	-0.1694	0.1689	0.0503	-9.6 to 10.52%
FML	695	-0.0022	-0.0021	52.9	35.8	11.2	-0.0283	0.0299	0.0090	-2.01 to 1.59%
FXMS	933	-0.0035	-0.0027	52.8	44.3	2.9	-0.1057	0.1105	0.0352	-7.31 to 6.77%
FIMS	931	0.0000	-0.0011	47.2	46.6	6.2	-0.1089	0.1089	0.0325	-6.61 to 6.39%
FXST	948	-0.0032	-0.0034	53.8	43	3.2	-0.1178	0.1307	0.0360	-7.54 to 6.86%
FIST	959	0.0000	0.0025	45.9	49.7	4.4	-0.1214	0.1239	0.0385	-7.45 to 7.95%
FEB	624	0.0000	0.0040	19.9	42.5	37.7	-0.0426	0.0715	0.0135	-2.3 to 3.1%
FLE	622	0.0000	0.0038	25.7	41	33.3	-0.0513	0.0616	0.0179	-3.2 to 3.96%
FAPH	866	0.0038	0.0037	37.9	56.5	5.7	-0.0562	0.0555	0.0165	-2.93 to 3.67%

Table 5.7: Continued.

Measurement	N	Median	Mean	% of Individuals			Minimum	Maximum	Std. Dev.	Confidence interval of 95%
				L>R	R>L	R=L				
FSIH	894	0.0020	0.0019	43.8	51.3	4.8	-0.0524	0.0515	0.0179	-3.39 to 3.77%
FMLP	747	0.0000	-0.0002	42.7	44	13.3	-0.0518	0.0484	0.0167	-3.36 to 3.32%
TML	576	0.0000	-0.0007	45.3	39.9	14.8	-0.0270	0.0282	0.0087	-1.81 to 1.67%
TXNF	814	-0.0027	-0.0013	51.1	45.7	3.2	-0.1038	0.1020	0.0333	-6.79 to 6.53%
TINF	834	0.0102	0.0111	37.9	58.2	4	-0.1272	0.1318	0.0400	-6.89 to 9.11%
TMLP	488	0.0000	0.0031	22.3	38.3	39.3	-0.0382	0.0445	0.0132	-2.33 to 2.95%
TMC	318	0.0000	0.0023	46.9	47.2	6	-0.0639	0.0688	0.0221	-4.19 to 4.65%
TLC	324	0.0043	0.0038	39.2	54.3	6.5	-0.0685	0.0715	0.0233	-4.28 to 5.04%
CZL	661	0.0000	0.0001	25.3	26.5	48.3	-0.0432	0.0500	0.0128	-2.55 to 2.57%
CZB	599	0.0000	-0.0051	33.6	19.4	47.1	-0.0800	0.0852	0.0228	-5.07 to 4.05%
CZH	691	0.0000	0.0020	25.8	33.3	41	-0.0660	0.0690	0.0216	-4.12 to 4.52%
TZL	630	0.0000	-0.0020	32.5	23.7	43.8	-0.0690	0.0715	0.0179	-3.78 to 3.38%
TZB	646	0.0000	-0.0005	27.7	26.9	45.4	-0.0780	0.0800	0.0234	-4.73 to 4.63%
TZH	660	0.0000	-0.0018	24.4	20.3	55.3	-0.0667	0.0625	0.0226	-4.7 to 4.34%
MT1L	556	-0.0033	-0.0036	57.7	36.9	5.4	-0.0472	0.0412	0.0140	-3.16 to 2.44%
MT2L	347	0.0013	0.0014	43.8	50.4	5.8	-0.0345	0.0349	0.0125	-2.36 to 2.64%
MT3L	364	0.0000	0.0005	45.3	49.2	5.5	-0.0369	0.0340	0.0121	-2.37 to 2.47%
MT4L	356	0.0014	0.0015	42.4	52.2	5.3	-0.0412	0.0441	0.0145	-2.75 to 3.05%
MT5L	378	0.0028	0.0020	45	52.4	2.6	-0.0452	0.0462	0.0169	-3.18 to 3.58%
Cranium	57	-0.0006	0.0001	52.6	47.4	0	-0.0317	0.0282	0.0115	-2.29 to 2.31%
Cranium: Orbit	202	0.0013	0.0017	42.1	57.4	0.5	-0.0420	0.0316	0.0112	-2.07 to 2.41%
Cranium: Facial	125	0.0028	0.0033	37.6	62.4	0	-0.0242	0.0329	0.0096	-1.59 to 2.25%
Cranium: Temporal	546	0.0027	0.0024	46.9	53.1	0	-0.1453	0.2001	0.0457	-8.9 to 9.38%
Cranium: Base	215	-0.0012	0.0002	54.9	45.1	0	-0.0483	0.0504	0.0167	-3.32 to 3.36%
Cranium: Vault	328	0.0025	0.0037	35.4	63.7	0.9	-0.0381	0.0375	0.0102	-1.67 to 2.41%
Mandible	306	-0.0008	0.0000	52.3	47.7	0	-0.0539	0.0620	0.0182	-3.64 to 3.64%
Clavicle	270	0.0032	0.0026	45.6	54.4	0	-0.1036	0.0802	0.0309	-5.92 to 6.44%
Scapula	65	0.0093	0.0093	24.6	75.4	0	-0.0604	0.0488	0.0194	-2.95 to 4.81%

Table 5.7: Continued.

Measurement	N	Median	Mean	% of Individuals			Minimum	Maximum	Std. Dev.	Confidence
				L>R	R>L	R=L				Interval of 95%
Humerus	305	0.0151	0.0151	13.8	86.2	0	-0.0282	0.0572	0.0149	-1.47 to 4.49%
Radius	229	0.0101	0.0115	25.8	74.2	0	-0.0391	0.0584	0.0172	-2.29 to 4.59%
Ulna	212	0.0106	0.0117	28.3	71.7	0	-0.0367	0.0659	0.0201	-2.85 to 5.19%
Metacarpals	154	0.0036	0.0034	33.1	66.9	0	-0.0254	0.0311	0.0094	-1.54 to 2.22%
Pelvic girdle	35	0.0054	0.0016	42.9	57.1	0	-0.0454	0.0359	0.0158	-3 to 3.32%
Sacrum	232	0.0036	0.0014	44.8	55.2	0	-0.0940	0.0839	0.0273	-5.32 to 5.6%
Os coxae	53	0.0031	0.0023	37.7	62.3	0	-0.0419	0.0339	0.0144	-2.65 to 3.11%
Femur	374	0.0006	0.0010	47.1	52.7	0.3	-0.0267	0.0317	0.0100	-1.9 to 2.1%
Tibia	192	0.0028	0.0029	40.1	59.9	0	-0.0351	0.0339	0.0125	-2.21 to 2.79%
Tarsals	417	-0.0014	-0.0014	54.4	44.1	1.4	-0.0348	0.0249	0.0093	-2 to 1.72%
Metatarsals	139	0.0014	0.0010	42.4	57.6	0	-0.0251	0.0260	0.0079	-1.48 to 1.68%
Upper Limb	64	0.0120	0.0101	25	75	0	-0.0264	0.0456	0.0139	-1.77 to 3.79%
Lower Limb	126	0.0023	0.0020	43.7	56.3	0	-0.0160	0.0218	0.0078	-1.36 to 1.76%
Upper long bone lengths	205	0.0084	0.0078	16.1	82.4	1.5	-0.0254	0.0259	0.0086	-0.94 to 2.5%
Lower long bone lengths	442	-0.0013	-0.0015	58.1	40.3	1.6	-0.0219	0.0163	0.0068	-1.51 to 1.21%
Midshafts	370	0.0131	0.0130	20.8	79.2	0	-0.0327	0.0562	0.0167	-2.04 to 4.64%
Upper limb midshafts	592	0.0214	0.0206	19.1	80.9	0	-0.0573	0.0950	0.0248	-2.9 to 7.02%
Lower limb midshafts	698	0.0015	0.0017	47.3	52.7	0	-0.0531	0.0730	0.0195	-3.73 to 4.07%
Shoulder	44	0.0150	0.0125	11.4	88.6	0	-0.0461	0.0460	0.0173	-2.21 to 4.71%
Elbow	176	0.0088	0.0080	31.8	68.2	0	-0.0468	0.0551	0.0181	-2.82 to 4.42%
Sacro-iliac joint	204	0.0050	0.0041	42.6	57.4	0	-0.1046	0.1001	0.0359	-6.77 to 7.59%
Hip	455	0.0026	0.0019	41.5	58.5	0	-0.0270	0.0347	0.0104	-1.89 to 2.27%
Knee	194	0.0033	0.0032	35.6	64.4	0	-0.0305	0.0307	0.0100	-1.68 to 2.32%

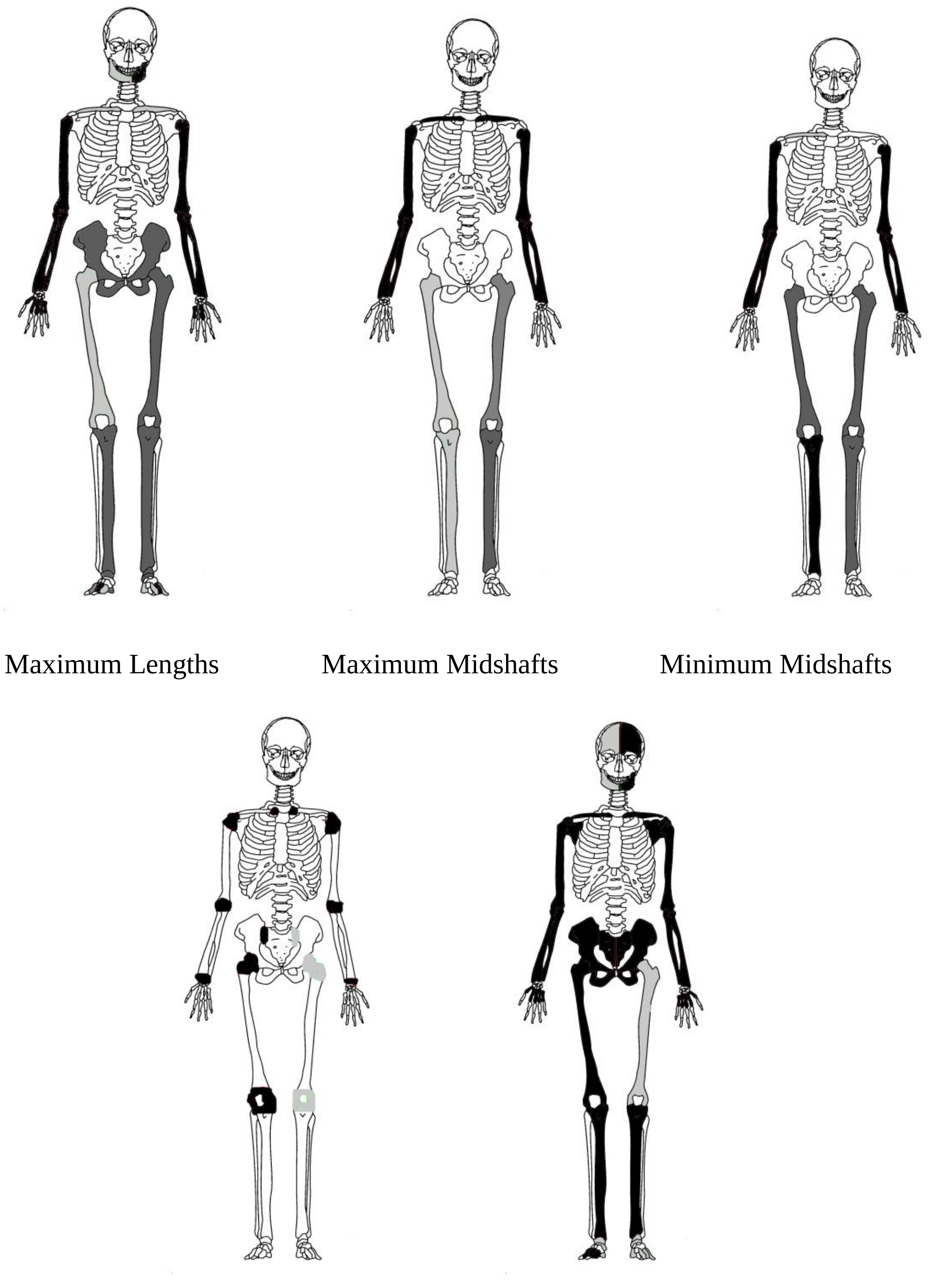

Figure 5.1 Pictorial representation of directional asymmetry. Adults are represented on the right side of the skeleton, with subadults on the left. Black signifies right-sided asymmetry, light grey left, and dark grey is symmetry.

The average overall median directional asymmetry for subadults was found to be similar to that of adults at 0.39%, with a 95% confidence interval of between -5.69 to 6.53% ($\overline{x}$ =0.42% and σ=3.06%) (see Table 5.8). Similar to the adult sample, when the extent of directionality is taken into account, subadults had a total of 15 measurements with medians favouring the left side, 43 measurements favouring the right side, and 27 measurements with an average median at zero. Specific element indices indicate that the viscerocranium, femur, tarsals and metatarsals were found to favour the left side, while all other whole elements favoured the right (see above Figures 5.1). Further, both the hip and the knee were found to be left-sided in subadults. The cranium had a mixture of directionality and symmetry with four measurements to the left, two symmetrical, and three to the right. The mandible was right-sided in all measurements, apart from minimum ramus breadth. Similar to the adults, the upper limb and shoulder were found to be mainly right-side dominant in all but four measurements, which were clavicular length and medial curvature of the left side and glenoid breadth and the radial head, which favoured symmetry. Unlike the adults, metacarpal lengths showed a mixture of directionality and symmetry, with MC2L to the left, MC1L and MC4L symmetrical and MC3L and MC5L to the right side. Also, the juvenile sacral alae were found to favour the right, unlike the adults which favour the left. The *os coxae* was symmetrical in iliac height and auricular surface breadth, right dominant in iliac breadth and ischial length, and left dominant in auricular surface length. Similar to the adults, the lower limbs and ankle of the subadults favoured symmetry. The only directional measurements for the lower limb were femoral maximum subtrochanteric diameter and width of the proximal end, which favoured the left side, and minimum subtrochanteric diameter, which was right-sided. For the tibia, medio-lateral breadth of the proximal end and anterior-posterior diameter of the medial condyle were right-side dominant and the antero-posterior diameter of the lateral condyle favoured the left. For the tarsals, the maximum length of the calcaneus was to the left side. Finally, there was a mixture of dominance and symmetry in the metatarsal lengths, with MT1 and 2 symmetrical, MT3 to the right side, and MT4 and 5 to the left.

The measurements with the highest median DA favouring the left side were CMAH (-1.01%), CVMC (-0.85%), and MIRB (-0.7%). The highest levels of DA in a measurement favouring the right were SAL (2.67%), RXMS (2.11%), and CMPL (2.15%). The majority of those measurements that had an average median of zero could be found in the femur and tibia. For calculated indices, scores were found to have weak left-sided directionality similar to those of the adults. The viscerocranium (-0.28%), femur (-0.25%) and lower long bone lengths (-0.14%) had the highest medians favouring the left side. Those that were right-side dominant include the shoulder (1.85%), radius (1.72%) and the upper limb (1.69%). Measurements with the largest range of asymmetry scores, those with high standard deviations, were CVLC (13.12%), CDGL (7.92%), and CVMC (6.68%). The most stable measurements, those exhibiting the lowest standard deviation, were the long bone lengths including FML (0.81%), TML (0.9%) and RML (1.04%). Similar to the adults, indices with the highest standard deviation for subadults include temporal region of the cranium (3.49%), clavicle (2.6%), and sacrum (2.6%). Those indices with the lowest standard deviation include the radius (0.28%), metacarpals (0.62%) and lower long bone lengths (0.66%).

By excluding the extent of directionality as a factor and calculating dominance by the overall number of individuals favouring one side over the other, 28 measurements were found to be left-side dominant, 52 favour the right, and only 5 were found to be symmetrical (see Table 5.8). Like the adults, and similar to the extent of directionality, subadult upper limbs, hands and shoulder were found to be overwhelmingly right-side dominant in all measurements, with the exceptions of clavicular length and medial curvature, glenoid breadth, and MC2 length, which were to the left side. The remaining elements demonstrated a mixture of right and left sidedness, with the only symmetrical measurements being MC4 length, auricular surface breadth, iliac height, femoral antero-posterior head diameter, and the maximum height of the talus. Those measurements that were largely symmetrical, having less than a 10% difference between the number of individuals favouring one side of the other (excluding symmetrical individuals), include CFMTB, COCL, RGH, MC1L, MC2L, SZAB, OCASH, FSMLD, FSIH, TXNF, TZL, and MT1L. Twelve measurements were found to be highly directional, in that there was a 50% or more difference in the number of individuals favouring the right side over the left, including CMPL, SAL, HML, HDT, HSMLD, HGT, RML, RXMS, RSMLD, RMLD, UML, and OCIB. .

Table 5.8: Results for directional asymmetry in subadults.

Measurement	N	Median	Mean	% of Individuals			Minimum	Maximum	Std. Dev.	Confidence Interval of 95%
				Left	Right	Zero				
CFMTN	115	-0.0018	0.0004	50.4	40	9.6	-0.0332	0.0348	0.0139	-2.74 to 2.82%
CMAH	141	-0.0101	-0.0080	60.3	34.8	5	-0.1089	0.0875	0.0355	-7.9 to 6.3%
CECMIS	120	-0.0041	-0.0037	60	36.7	3.3	-0.0461	0.0445	0.0185	-4.07 to 3.33%
CFMTB	45	0.0000	0.0026	35.6	37.8	26.7	-0.0404	0.0529	0.0204	-3.82 to 4.34%
CMPL	174	0.0194	0.0254	22.4	71.3	6.3	-0.1172	0.1513	0.0433	-6.12 to 11.2%
CMPB	174	0.0086	0.0116	36.2	56.9	6.9	-0.1463	0.1764	0.0547	-9.78 to 12.1%
CMSAST	132	0.0121	0.0106	37.9	58.3	3.8	-0.1184	0.1227	0.0412	-7.18 to 9.3%
CDGL	136	-0.0060	-0.0084	50.7	44.9	4.4	-0.2412	0.2364	0.0936	-19.56 to 17.88%
COCL	168	0.0000	0.0009	47.6	45.8	6.5	-0.0968	0.1044	0.0390	-7.71 to 7.89%
MAL	163	0.0012	0.0019	41.1	54.6	4.3	-0.0335	0.0346	0.0117	-2.15 to 2.53%
MRH	176	0.0046	0.0039	38.1	58	4	-0.0347	0.0491	0.0168	-2.97 to 3.75%
MXRB	144	0.0026	0.0016	44.4	52.1	3.5	-0.0781	0.0671	0.0286	-5.56 to 5.88%
MIRB	217	-0.0070	-0.0042	53.9	41	5.1	-0.1032	0.0848	0.0310	-6.62 to 5.78%
CVML	144	-0.0052	-0.0041	56.3	35.4	8.3	-0.0554	0.0456	0.0189	-4.19 to 3.37%
CVXMS	279	0.0129	0.0086	40.5	52.7	6.8	-0.1694	0.1782	0.0604	-11.22 to 12.94%
CVWA	159	0.0175	0.0175	33.3	60.4	6.3	-0.1683	0.1917	0.0632	-10.89 to 14.39%
CVWS	156	0.0171	0.0191	32.1	58.3	9.6	-0.1457	0.1566	0.0561	-9.31 to 13.13%
CVMC	70	-0.0085	0.0002	51.4	41.4	7.1	-0.2085	0.1999	0.0792	-15.82 to 15.86%
CVLC	64	0.0115	0.0065	43.8	53.1	3.1	-0.2812	0.3390	0.1312	-25.59 to 26.89%
SGL	188	0.0100	0.0106	36.7	61.7	1.6	-0.0624	0.0796	0.0293	-4.8 to 6.92%
SGB	190	0.0000	-0.0041	49.5	41.6	8.9	-0.1126	0.0870	0.0378	-7.97 to 7.15%
SAL	75	0.0267	0.0254	22.7	72	5.3	-0.0968	0.1263	0.0412	-5.7 to 10.78%
HML	195	0.0036	0.0046	27.2	56.9	15.9	-0.0216	0.0279	0.0107	-1.68 to 2.6%
HXMS	300	0.0142	0.0128	31	60.7	8.3	-0.0795	0.1064	0.0343	-5.58 to 8.14%
HIMS	299	0.0090	0.0061	37.5	53.8	8.7	-0.1072	0.1178	0.0400	-7.39 to 8.61%
HDT	250	0.0162	0.0171	25.6	66.8	7.6	-0.0840	0.0994	0.0347	-5.23 to 8.65%
HSIH	79	0.0102	0.0099	35.4	60.8	3.8	-0.0825	0.0713	0.0273	-4.47 to 6.45%
HAPH	72	0.0078	0.0078	31.9	56.9	11.1	-0.0593	0.0690	0.0264	-4.5 to 6.06%

Table 5.8: Continued.

Measurement	N	Median	Mean	% of Individuals			Minimum	Maximum	Std. Dev.	Confidence Interval of 95%
				Left	Right	Zero				
HSMLD	157	0.0094	0.0081	29.9	67.5	2.5	-0.0612	0.0658	0.0221	-3.61 to 5.23%
HSMLP	156	0.0092	0.0084	35.9	62.2	1.9	-0.0651	0.0761	0.0264	-4.44 to 6.12%
HGT	42	0.0087	0.0168	26.2	64.3	9.5	-0.1097	0.1625	0.0438	-7.08 to 10.44%
RML	124	0.0044	0.0043	22.6	60.5	16.9	-0.0320	0.0295	0.0104	-1.65 to 2.51%
RXMS	273	0.0211	0.0185	31.1	61.9	7	-0.0966	0.1364	0.0463	-7.41 to 11.11%
RIMS	269	0.0146	0.0101	35.3	54.3	10.4	-0.1301	0.1473	0.0483	-8.65 to 10.67%
RGH	118	0.0000	0.0044	40.7	44.9	14.4	-0.0852	0.0886	0.0360	-6.76 to 7.64%
RSMLD	85	0.0121	0.0126	25.9	57.6	16.5	-0.0601	0.0840	0.0281	-4.36 to 6.88%
RMLD	31	0.0085	0.0070	32.3	67.7	0	-0.0384	0.0547	0.0233	-3.96 to 5.36%
UML	110	0.0051	0.0041	26.4	60.9	12.7	-0.0319	0.0255	0.0106	-1.71 to 2.53%
UPL	105	0.0030	0.0040	31.4	52.4	16.2	-0.0353	0.0251	0.0119	-1.98 to 2.78%
UXMS	261	0.0088	0.0058	42.1	51.3	6.5	-0.1386	0.1364	0.0468	-8.78 to 9.94%
UIMS	267	0.0177	0.0198	34.8	57.7	7.5	-0.1823	0.2007	0.0668	-11.38 to 15.34%
URN	215	0.0045	0.0044	42.3	51.6	6	-0.1054	0.0943	0.0373	-7.02 to 7.9%
UOW	220	0.0115	0.0116	34.5	59.1	6.4	-0.1112	0.1120	0.0416	-7.16 to 9.48%
UCH	200	0.0039	0.0051	37.5	51.5	11	-0.0627	0.0874	0.0278	-5.05 to 6.07%
MC1L	60	0.0000	0.0012	45	48.3	6.7	-0.0484	0.0427	0.0201	-3.9 to 4.14%
MC2L	77	-0.0016	0.0019	50.6	46.8	2.6	-0.0355	0.0354	0.0159	-2.99 to 3.37%
MC3L	74	0.0025	0.0020	44.6	51.4	4.1	-0.0309	0.0390	0.0154	-2.88 to 3.28%
MC4L	70	0.0000	0.0001	45.7	45.7	8.6	-0.0335	0.0370	0.0155	-3.09 to 3.11%
MC5L	48	0.0039	0.0037	37.5	58.3	4.2	-0.0221	0.0339	0.0136	-2.35 to 3.09%
SZAB	140	0.0050	0.0019	45.7	50.7	3.6	-0.0993	0.0889	0.0424	-8.29 to 8.67%
SZS1	157	0.0107	0.0119	36.9	55.4	7.6	-0.0645	0.0948	0.0318	-5.17 to 7.55%
OCH	158	0.0000	0.0000	36.7	37.3	25.9	-0.0327	0.0302	0.0126	-2.52 to 2.52%
OCIB	115	0.0026	0.0041	26.1	54.8	19.1	-0.0279	0.0357	0.0115	-1.89 to 2.71%
OCIS	180	0.0014	0.0005	42.8	51.7	5.6	-0.0400	0.0393	0.0130	-2.55 to 2.65%
OCASH	306	-0.0012	0.0006	50	48	2	-0.1911	0.1953	0.0653	-13 to 13.12%
OCASB	211	0.0000	0.0023	47.4	47.4	5.2	-0.0984	0.1012	0.0362	-7.01 to 7.47%
FML	198	0.0000	-0.0019	48	31.3	20.7	-0.0252	0.0212	0.0081	-1.81 to 1.43%

Table 5.8: Continued.

Measurement	N	Median	Mean	% of Individuals			Minimum	Maximum	Std. Dev.	Confidence Interval of 95%
				Left	Right	Zero				
FXMS	295	0.0000	0.0009	42	48.1	9.8	-0.0937	0.0800	0.0307	-6.05 to 6.23%
FIMS	299	0.0000	-0.0049	49.8	39.5	10.7	-0.0922	0.1014	0.0325	-6.99 to 6.01%
FXST	312	-0.0046	-0.0046	51.6	41	7.4	-0.1182	0.1136	0.0396	-8.38 to 7.46%
FIST	316	0.0053	0.0084	43.4	51.9	4.7	-0.1161	0.1404	0.0470	-8.56 to 10.24%
FSMLD	110	0.0000	-0.0002	47.3	44.5	8.2	-0.0488	0.0574	0.0203	-4.08 to 4.04%
FEB	75	0.0000	0.0003	45.3	38.7	16	-0.0289	0.0368	0.0139	-2.75 to 2.81%
FLE	122	0.0000	0.0025	38.5	47.5	13.9	-0.0561	0.0642	0.0220	-4.15 to 4.65%
FAPH	162	0.0000	0.0005	45.7	46.3	8	-0.0575	0.0525	0.0202	-3.99 to 4.09%
FSIH	153	0.0000	-0.0008	46.4	45.1	8.5	-0.0523	0.0533	0.0186	-3.8 to 3.64%
FMLP	255	-0.0020	-0.0026	53.3	40	6.7	-0.0524	0.0512	0.0172	-3.7 to 3.18%
TML	174	0.0000	-0.0008	43.1	35.1	21.8	-0.0267	0.0226	0.0090	-1.88 to 1.72%
TXNF	276	0.0000	-0.0001	48.2	45.3	6.5	-0.0946	0.0941	0.0361	-7.23 to 7.21%
TINF	275	0.0000	0.0051	41.8	49.1	9.1	-0.1313	0.1178	0.0423	-7.95 to 8.97%
TSMLP	87	0.0028	0.0033	41.4	52.9	5.7	-0.0605	0.0588	0.0213	-3.93 to 4.59%
TMLP	89	0.0000	0.0005	40.4	49.4	10.1	-0.0359	0.0275	0.0146	-2.87 to 2.97%
TMC	52	0.0062	0.0044	32.7	55.8	11.5	-0.0610	0.0416	0.0221	-3.98 to 4.86%
TLC	55	-0.0046	-0.0028	56.4	43.6	0	-0.0536	0.0481	0.0225	-4.78 to 4.22%
CZL	121	-0.0018	-0.0025	52.1	28.1	19.8	-0.0305	0.0355	0.0127	-2.79 to 2.29%
CZB	102	0.0000	-0.0010	42.2	37.3	20.6	-0.0505	0.0392	0.0214	-4.38 to 4.18%
CZH	103	0.0000	0.0036	39.8	46.6	13.6	-0.0427	0.0625	0.0220	-4.04 to 4.76%
TZL	106	0.0000	0.0002	40.6	39.6	19.8	-0.0508	0.0513	0.0171	-3.4 to 3.44%
TZB	97	0.0000	-0.0004	41.2	36.1	22.7	-0.0439	0.0645	0.0231	-4.66 to 4.58%
TZH	107	0.0000	0.0005	38.3	38.3	23.4	-0.0619	0.0668	0.0255	-5.05 to 5.15%
MT1L	111	0.0000	0.0003	45	45.9	9	-0.0415	0.0404	0.0148	-2.93 to 2.99%
MT2L	69	0.0000	-0.0010	49.3	43.5	7.2	-0.0360	0.0412	0.0162	-3.34 to 3.14%
MT3L	62	0.0036	0.0035	35.5	56.5	8.1	-0.0251	0.0372	0.0131	-2.27 to 2.97%
MT4L	59	-0.0045	-0.0031	57.6	33.9	8.5	-0.0331	0.0291	0.0148	-3.27 to 2.65%
MT5L	56	-0.0009	0.0007	50	44.6	5.4	-0.0455	0.0395	0.0184	-3.61 to 3.75%
Cranium	12	0.0067	0.0050	33.3	66.7	0	-0.0505	0.0355	0.0212	-3.74 to 4.74%

Table 5.8: Continued.

Measurement	N	Median	Mean	% of Individuals			Minimum	Maximum	Std. Dev.	Confidence Interval of 95%
				Left	Right	Zero				
Cranium: Facial	19	-0.0028	-0.0041	73.7	26.3	0	-0.0207	0.0249	0.0115	-2.71 to 1.89%
Cranium: Temporal	95	0.0140	0.0119	30.5	69.5	0	-0.0993	0.1046	0.0349	-5.79 to 8.17%
Mandible	119	0.0007	0.0011	49.6	50.4	0	-0.0429	0.0437	0.0157	-3.03 to 3.25%
Clavicle	44	0.0124	0.0105	29.5	70.5	0	-0.0402	0.0631	0.0260	-4.15 to 6.25%
Scapula	61	0.0113	0.0081	36.1	63.9	0	-0.0727	0.0678	0.0248	-4.15 to 5.77%
Humerus	21	0.0154	0.0131	14.3	85.7	0	-0.0142	0.0321	0.0121	-1.11 to 3.73%
Radius	2	0.0172	0.0172			0	0.0152	0.0192	0.0028	1.16 to 2.28%
Ulna	66	0.0071	0.0089	33.3	66.7	0	-0.0282	0.0652	0.0183	-2.77 to 4.55%
Metacarpals	16	0.0032	0.0011	37.5	62.5	0	-0.0107	0.0104	0.0062	-1.13 to 1.35%
Pelvic girdle	31	0.0047	0.0066	35.5	64.5	0	-0.0143	0.0354	0.0118	-1.7 to 3.02%
Sacrum	131	0.0040	0.0054	41.2	58	0.8	-0.0541	0.0720	0.0260	-4.66 to 5.74%
Os coxae	56	0.0036	0.0035	41.1	58.9	0	-0.0332	0.0396	0.0153	-2.71 to 3.41%
Femur	17	-0.0025	-0.0016	58.8	41.2	0	-0.0253	0.0172	0.0114	-2.44 to 2.12%
Tibia	16	0.0047	0.0042	37.5	62.5	0	-0.0122	0.0228	0.0095	-1.48 to 2.32%
Tarsals	50	-0.0008	-0.0010	54	46	0	-0.0190	0.0282	0.0097	-2.04 to 1.84%
Metatarsals	18	-0.0006	-0.0003	55.6	44.4	0	-0.0130	0.0117	0.0070	-1.43 to 1.37%
Upper Limb	1	0.0169	0.0169			0	0.0169	0.0169		
Lower Limb	6	0.0013	0.0007	33.3	66.7	0	-0.0156	0.0107	0.0090	-1.73 to 1.87%
Upper long bone lengths	59	0.0044	0.0047	28.8	71.2	0	-0.0285	0.0240	0.0089	-1.31 to 2.25%
Lower long bone lengths	117	-0.0014	-0.0014	56.4	38.5	5.1	-0.0176	0.0184	0.0066	-1.46 to 1.18%
Midshafts	102	0.0071	0.0085	30.4	69.6	0	-0.0271	0.0391	0.0145	-2.05 to 3.75%
Upper limb midshafts	182	0.0111	0.0128	28	72	0	-0.0475	0.0797	0.0230	-3.32 to 5.88%
Lower limb midshafts	224	-0.0003	-0.0002	51.3	48.7	0	-0.0652	0.0636	0.0187	-3.76 to 3.72%
Shoulder	12	0.0185	0.0168	16.7	83.3	0	-0.0123	0.0339	0.0155	-1.42 to 4.78%
Elbow	54	0.0042	0.0061	40.7	59.3	0	-0.0251	0.0634	0.0198	-3.35 to 4.57%
Hip	116	-0.0002	0.0003	50.9	49.1	0	-0.0442	0.0349	0.0132	-2.61 to 2.67%
Knee	11	-0.0011	-0.0009	63.6	36.4	0	-0.0145	0.0094	0.0068	-1.45 to 1.27%

5.5.2 Population Comparisons by Sex

Females were found to have highest median directional asymmetry scores and males the lowest. Males had an average median of 0.35% with a 95% confidence interval range of between -5.78% and 6.59% ($\bar{x}$ =0.4% and σ=3.09%), and females were at 0.41% and a range of -5.76% to 6.63% ($\bar{x}$ =0.43% and σ=3.1%) (see Table AP 6.1). Further, females exhibited more right-sided traits than males. Females had 60 measurements with medians to the right, 15 to the left, and 26 at zero, while males had 54 measurements to the right side, 16 to the left, and 31 at zero. Males and females differed in directionality in COBH, COCL, COPO, CVLC, and OCPL (with females right-sided and males left-sided). Both sexes had four indices to the left and 28 to the right, differing in direction only in the cranium (females right-sided and males left) and mandible (males right-sided and females left). A comparison of the total percentages of individuals from the whole sample population with right- and left-side dominance also indicate that females possessed more directional asymmetry than did males (see Tables 5.9 and AP 6.2). There was a 10% or more increase in the percentage of females for sidedness over that of males for measurements CBAPO, HML, RML, UML, UPL, MC3L, MC5L, MT1L, and for indices of the viscerocranium, metacarpals, os coxae, and the upper long bone lengths. Males were only found to have a similar increase over females in HXMS, HGT, and the index for the elbow. Also, with a difference in the percentage of individuals with a particular sidedness of 10% or over, males and females differed in sidedness in COBH, OCPL, the cranium, and the mandible.

Results from Mann-Whitney *U*-tests indicate that significant differences in directional asymmetry between males and females were found in 19 measurements and six indices (see Tables 5.10 and AP 7.1). Of the measurements, 16 were in the upper limb, shoulder and hand, and one measurement in the cranium, one in the tibia, and one in the foot. There were no significant differences in the scapula, sacrum, *os coxae*, femur, and tarsals. Although there were no significant differences in single measurements for the mandible, the overall mandibular index was found to be significantly different.

Table 5.9: Measurements with a 10% or more difference between males and females for actual counts of individual directionality within each population.

	Male %			Female %		
Measurement	L>	R>	R=L	L>	R>	R=L
COBH	52.3	43.1	4.6	42	55	3
CBAPO	54.8	42.3	2.9	64.9	32.8	2.2
HML	17.6	71.4	10.9	4.6	90.2	5.2
HXMS	20.4	76.4	3.2	29.2	66.1	4.7
HGT	20.1	76.3	3.6	30.3	66.3	3.4
RML	23.8	58.1	18.1	13.8	76	10.2
UML	26.8	60.4	12.8	12.4	81.4	6.2
UPL	25.8	60.3	13.9	17.4	71.9	10.8
MC3L	47.5	48.5	4	32.2	63.8	4
MC5L	45.3	51.4	3.3	32	61.5	6.5
OCPL	54.5	43.2	2.3	41.2	58.8	0
MT1L	54.5	40.3	5.2	64.7	29.4	5.9
Cranium	58.1	41.9	0	46.2	53.8	0
Cranium: Facial	42.5	57.5	0	30.8	69.2	0
Mandible	47.4	52.6	0	58.6	41.4	0
Metacarpals	40.6	59.4	0	20.7	79.3	0
Os coxae	44.4	55.6	0	23.5	76.5	0
Upper long bone lengths	19.3	78.7	2	7.4	92.6	0
Elbow	27.8	72.2	0	38.2	61.8	0

Table 5.10: Significant results for directional asymmetry from Mann Whitney-*U* tests comparing males and females. (*p significant after a Bonferroni adjustment).

Measurement	Female N	Male N	Z	P
CFMTN	255	343	-2.4712	0.0135
CVXMS	360	498	-3.1037	0.0019
CVIMS	364	501	-3.3987	0.0007
CVLC	162	289	2.0245	0.0429
HML	194	357	5.8968	<0.00001*
HXMS	363	529	-4.6640	<0.00001*
HIMS	363	524	-3.7898	0.0002*
HDT	357	515	-3.9362	0.0001*
HGT	178	304	-4.4146	<0.00001*
RML	167	298	5.0119	<0.00001*
RGH	127	228	2.1210	0.0339
UML	113	250	4.8269	<0.00001*
UPL	167	302	4.4448	<0.00001*
UXMS	317	481	2.5711	0.0101

Table 5.10: Continued.

Measurement	Female N	Male N	Z	P
MC2L	207	333	2.5073	0.0122
MC3L	199	324	3.7479	0.0002*
MC5L	169	276	2.5900	0.0096
TMLP	168	316	2.3058	0.0211
MT1L	204	347	-2.0982	0.0359
Mandible	133	173	-2.0717	0.0383
Humerus	108	196	-4.4240	<0.00001*
Metacarpals	58	96	3.1882	0.0014*
Upper long bone lengths	54	150	4.1050	<0.00001*
Midshafts	138	232	-2.8827	0.0039
Upper limb midshafts	220	371	-2.6238	0.0087

5.5.3 Population Comparisons by Age-at-Death

Both adults and subadults had similar average median directional asymmetry scores (see Table AP 6.3). The average median DA for subadults was found to be 0.4% with a 95% confidence interval range of -5.79 to 6.6% ($\bar{x}$ =0.37% and σ=3.1%) and an average median of 0.43% and a range of -5.76 to 6.68% ($\bar{x}$ =0.46% and σ=3.11%) for adults. Mann Whiney-*U* tests found significant differences in 24 of the 83 measurements between the groupings of subadult and adult population (see Tables 5.11 and AP 7.2). The majority of the differences were in the upper body, with five in the skull, four in the shoulder, eight in the upper limb, three in the pelvic girdle, and five in the lower limb and foot. No significant differences were found in the metacarpals or the talus. Subadults had more measurements with average left-sided medians and more that were symmetrical than those found in adults. Subadults had 39 measurements to the right side, 15 to the left and 21 that were symmetrical, while adults had 48 to the right side, 11 to the left, and 21 that were symmetrical (see Table AP 6.3).

Table 5.11: Significant results for directional asymmetry from Mann Whitney-*U* tests comparing adults with subadults. (*p significant after a Bonferroni adjustment).

Measurement	Adult N	Subadult N	Z	p-value
CFMTN	598	115	2.3544	0.0186
CMAH	637	141	2.7630	0.0057
CECMIS	363	120	2.3370	0.0194
CMPL	736	174	-4.7129	<0.00001*
MAL	528	163	-3.2083	0.0013
CVML	484	144	-3.5482	0.0004*
SGB	511	190	2.7749	0.0055
SAL	227	75	-2.6036	0.0092
HML	552	195	6.0171	<0.00001*
HXMS	895	300	4.3208	<0.00001*
HIMS	890	299	3.2866	0.001
HAPH	526	72	2.0376	0.0416
RXMS	850	273	2.7640	0.0057
UML	364	110	2.0110	0.0443
UPL	470	105	2.3100	0.0209
UXMS	800	261	3.8524	0.0001*
SZS1	648	157	-3.7220	0.0002*
OCIB	186	115	-2.5044	0.0123
OCASH	811	306	1.9884	0.0468
FEB	624	75	2.4901	0.0128
FMLP	747	255	2.0731	0.0382
CZL	661	121	2.7556	0.0059
MT1L	556	111	-2.4359	0.0149
MT4L	356	59	2.3206	0.0203

Further comparisons of dominance based on the total percentages of individuals with maximum long bone and clavicular lengths that were left-side dominant, right-sided, and symmetrical were made between specific age groups (Table 5.12). (For a complete list of percentages for all measurements see Tables AP 6.5 and AP 6.7). It was found that for the maximum length of the clavicle had left-side dominance for all age groups, with the highest percentage of left-side dominance in the middle adult age group at 65.3%. From late childhood to the mature adults there is an increase in the number of individuals expressing symmetry and a decrease in right-sidedness. For the humerus, those individuals in the foetal to infant age group were found to be decidedly left-side dominant, but by early childhood this directionality changed to right-sidedness, with an increase in individuals showing symmetry. From adolescent to mature adulthood, 75-

84% of the population has right-sided directionality. In the radial length of the foetal to infant group was found to be only slightly right-side biased, 45% right and 40% left-sided. The radius was found to become more right-sided with age, as 59.8%-69.7% of adolescent to mature adults are right-sided. Similarly, the ulna shows right side directionality in all age groups, with a slight increase from 57.1% of those in the foetal to infant age group to 60-75.6% of those in the remaining groups. The femur and tibia were found to have maximum lengths favouring the left side. The femur lacked dominance in the foetal to infant group, but 44-54% of individuals from the early childhood to mature adult groupings are left-sided. Finally, all age groupings were found to be left-side dominant for the maximum length of the tibia, with 42.4-46.4% of the individuals being left-sided, except for those in the adolescent group which were right-side dominant.

Table 5.12: Directionality expressed as a percentage of individuals from specific age groups for maximum long bone lengths.

		Measurement (% of individuals)					
Age Group	Direction	CVML	HML	RML	UML	FML	TML
Foetal to Infant	L>	58.8	66.7	40	42.9	47.4	43.8
	R>	41.2	29.6	45	57.1	47.4	37.5
	R=L	0	3.7	15	0	5.3	18.8
Early Childhood	L>	55.8	25.7	25	26.2	44.3	45.2
	R>	44.2	47.1	60	64.3	27.1	29
	R=L	0	27.1	15	9.5	28.6	25.8
Late Childhood	L>	54.8	23.2	19.5	18.2	54.4	45.3
	R>	33.3	64.3	63.4	60.6	30.9	35.9
	R=L	11.9	12.5	17.1	21.2	14.7	18.8
Adolescent	L>	57.6	9.5	8.7	28.6	43.9	34.4
	R>	21.2	81	69.6	57.1	31.7	43.8
	R=L	21.2	9.5	21.7	14.3	24.4	21.9
Young Adult	L>	62.1	10	17	17.1	52.1	42.4
	R>	19.7	84.3	67.9	75.6	43.7	33.9
	R=L	18.2	5.7	15.1	7.3	4.2	23.7
Middle Adult	L>	65.3	14.6	23.6	24.9	52.4	45.9
	R>	23.3	75	59.8	65.7	33.8	40.1
	R=L	11.5	10.4	16.5	9.5	13.7	14
Mature Adult	L>	57.2	11.2	15.8	20	54	46.4
	R>	29.6	81.1	69.7	67.5	36.7	41.6
	R=L	13.2	7.7	14.5	12.5	9.3	12

There was found to be little difference in either average median directional asymmetry scores or in asymmetry ranges for adults of specific adult age groups (see Table AP 6.4). The average mean median DA for young adults was 0.35% and a range with a 95% confidence interval ranging from -5.68 to 6.49% ($\overline{x}$ =0.4% and σ=3.04%), for middle adults the average median was also 0.35% with a range of -5.7 to 6.5% ($\overline{x}$ =0.4% and σ =3.05%), and for mature adults the average median was 0.39% with a range of -5.98 to 6.89% ($\overline{x}$ =0.39% and σ=0.44%). Young adults had the highest number of measurements with average medians to the left or to the right side, with 59 to the right, 24 to the left, and 18 that were symmetrical. Middle adults and mature adults had similar in directionality with middle adults having 52 measurements to the right, 14 to the left and 35 symmetrical, and mature adults with 57 to the right, 17 to the left, and 27 symmetrical.

Overall, Kruskal-Wallis ANOVA tests indicate that between the adult age groups, six measurements and one index significantly differed between age groups (see Tables 5.13 and AP 7.3). Three of the significant differences in measurements were located in the upper limb, one in the *os coxae,* two in the metatarsals, and in the index for the knee. Of these, post-hoc tests (see Tables 5.14, AP 7.3 and the electronic appendix) found significant differences between age groupings in four measurements, three of which involved young adults and three mature adults.

Table 5.13: Significant results for directional asymmetry from Kruskal-Wallis ANOVA tests for between adult age groups. (*p significant after a Bonferroni adjustment).

Measurement	D	N	H	p-Value
HXMS	2	880	6.3046	0.0428
RGH	2	348	8.6062	0.0135
UPL	2	465	6.6984	0.0351
OCIB	2	184	11.1822	0.0037
MT2L	2	330	9.745	0.0077
MT4L	2	342	7.4922	0.0236
Knee	2	186	6.0724	0.048

Table 5.14: Significant differences in directional asymmetry from post-hoc tests between adult age groups. (MA=Mature Adult, MDA=Middle Adult, and YA=Young Adult).

Measurement/Index	Differences are Between:
RGH	MDA and MA
UPL	YA and MDA
OCIB	YA and MA
	MDA and MA
MT2L	YA and MA
	YA and MDA

The average median directional asymmetry scores for subadults varied more between the age groups than those of the adults. DA was found to rise with age, except for a slight drop during early childhood (see Table AP 6.6). Of all the age groups, the foetal to infant sample had the second to lowest mean median DA at 0.29% and the highest 95% confidence interval of between -6.67 and 7.28% ($\overline{x}$ =0.3% and σ=3.49%). The mean median DA for early childhood was the lowest for all subadult and adult age groups at 0.15% with a range of -5.91 to 6.35% ($\overline{x}$ =0.21% and σ=3.06%). The average median for late childhood was 0.44% with a range of -5.55 to 6.47% ($\overline{x}$ =0.46% and σ =3%). The adolescent age grouping had the highest average median DA, but the lowest range of all the subadult and adult age groups at 0.73% with a range of -5.11 to 6.53% ($\overline{x}$ =0.71% and σ=2.91%). Directionality for the foetal to infant group for measurements was relatively balanced with 17 to the right, 14 to the left, and 15 symmetrical. The early childhood sample had the highest number of left-side dominant measurements with 34 to the left, 31 to the right, and 19 symmetrical. Directionality then changes to right-side dominance in late childhood and adolescence. Late childhood was found to have 59 measurements to the right side, 18 to the left, and 18 symmetrical, while adolescents had 56 to the right, 13 to the left and 16 symmetrical.

Overall, Kruskal-Wallis ANOVA tests found significant differences in directional asymmetry between subadult age groupings in 12 measurements and three indices (see Tables 5.15 and AP 7.4). Of these significant differences, nine measurements were in the upper limb and shoulder and only three were in the lower limb. There were no differences found in the cranium, scapula, hands, pelvic girdle, tibia, tarsals, or metatarsals. Post-hoc tests indicate that the majority of these significant differences were either with adolescent or foetal to infant age groups (see Tables 5.16, AP 7.6, and the electronic appendix). The differences were predominantly between foetal to infant and adolescent, and between early childhood and adolescent. A further difference was found during post-hoc testing, although it did not differ in ANOVA testing, in minimum subtrochanteric diameter of the femur (FIST) between foetal to infant and adolescent groups.

Table 5.15: Significant results for directional asymmetry from Kruskal-Wallis ANOVA tests for between subadult age groups. (*p significant after a Bonferroni adjustment).

Measurement	d	N	H	p-Value
CVLC	2	64	10.2734	0.0059
HML	3	195	33.8653	<0.00001*
HXMS	3	300	9.6191	0.0221
HIMS	3	299	20.0691	0.0002*
HSMLD	3	157	17.9166	0.0005*
HSMLP	3	156	22.9516	<0.00001*
RML	3	124	10.2613	0.0165
RXMS	3	273	14.0534	0.0028
UXMS	3	261	10.3545	0.0158
FXST	3	312	10.8198	0.0127
FIST	3	316	7.5392	0.0566
FAPH	2	162	7.3284	0.0256
Mandible	3	119	8.3111	0.04
Midshafts	3	102	14.529	0.0023*
Upper limb midshafts	3	182	30.0557	<0.00001*

Table 5.16: Significant differences in directional asymmetry from post-hoc tests between subadult age groups. (*AD=Adolescent, LC=Late Childhood, EC=Early Childhood, and FI=Foetal to Infant).

Measurement/Index	Differences are Between:	P
CVLC	EC and LC	0.0074
HML	FI and AD	<0.00001
	FI and LC	0.0001
	EC and LC	0.0482
	EC and AD	0.0006
HIMS	FI and LC	0.0422
	FI and AD	0.0027
	EC and AD	0.0021
HSMLD	FI and AD	0.0085
	EC and AD	0.0006
HSMLP	FI and LC	0.0159
	FI and AD	0.006
	EC and LC	0.0033
	EC and AD	0.0034
RML	FI and AD	0.0276
RXMS	EC and LC	0.036
	EC and AD	0.0456
UXMS	EC and AD	0.0358
FXST	FI and EC	0.0232
	FI and AD	0.0083
FIST	FI and AD	0.049
FAPH	EC and AD	0.0213
Mandible	FI and LC	0.0246
Midshafts	FI and LC	0.0339
	FI and AD	0.0258
Upper limb midshafts	FI and LC	0.0035
	FI and AD	0.0006
	EC and LC	0.0014
	EC and AD	0.0001

5.5.4 Population Comparisons by Site

The highest average median directional asymmetry score for the adult population from a specific archaeological site was from Chelsea at 0.54% with a 95% confidence interval of -6.06 to 7.05% ($\bar{x}$ =0.5% and σ=3.28%), followed by Wolverhampton at 0.51% with a range of -6.57 to 7.61% ($\bar{x}$ =0.52% and σ=3.55%) and Hickleton at 0.48% with a range of -6.29 to 7.24% ($\bar{x}$ =0.48% and σ=3.38%) (see Table AP 6.8). The lowest average median DA score was found to be from Towton at 0.25% with a range of -5.89 to 6.38% ($\bar{x}$ =0.25% and σ=3.07%), followed by Blackfriars at 0.3% with a rage of -5.83 to 6.27 ($\bar{x}$ =0.22% and σ=3.02%), and Wharram Percy at 0.32% with a range of

-5.74 to 6.52% ($\overline{x}$ =0.39% and σ=3.07%). York Minster and Hereford had the lowest standard deviations, thus the lowest range, in population DA scores; while Wolverhampton had the highest range of asymmetry. Blackfriars had the most measurements with average medians that were left-sided with 38, while it had the lowest number to the right at 49 with only 14 symmetrical. Hickleton and Wolverhampton had the most measurements favouring the right side, with 63 and 62, respectively.

Population comparisons between adults from the 11 studied archaeological sites found significant differences from Kruskal-Wallis ANOVA tests for 25 measurements and six indices (see Tables 5.17 and AP 7.3). Of the measurements, five were in the skull, 11 in the upper limb and shoulder, one in the pelvic girdle, and eight in the lower limb and tarsals. There were no significant differences in measurements for the hand, sacrum, or metatarsals. Post-hoc analysis indicates that of these measurements and indices, 12 measurements and three indices had significant differences between specific sites (see Tables 5.18, AP 7.7, and the electronic appendix). Both Wolverhampton and Wharram Percy had the most significant differences when comparisons were made between them and another site, with 15 and 16 differences in DA, respectively. These sites were followed by Chichester with 11 and Fishergate with 10 differences. Hickleton and Towton had the lowest number of differences, both with two. The two sites with the most significant differences between each other were Wolverhampton and Wharram Percy, with four measurements differing in DA. Although not differing in overall site comparisons, further differences were found during post-hoc testing between specific sites in CVML, MC1L, and SZSIA.

Table 5.17: Significant results for directional asymmetry from Kruskal-Wallis ANOVA tests for between site comparisons for adults. (*p significant after a Bonferroni adjustment).

Measurement	D	N	H	p-Value
CFMTN	10	598	21.5646	0.0175
CMPL	10	736	55.8592	<0.00001*
COPO	8	360	16.3977	0.0370
CBZO	7	210	18.6423	0.0094
MRH	10	529	19.0492	0.0396
CVML	10	484	17.349	0.067
CVWA	10	550	18.902	0.0415
SGL	10	505	20.1713	0.0277
SGB	10	511	22.8778	0.0112
SCL	10	216	18.7451	0.0436
HML	10	552	21.8123	0.0161
HXMS	10	895	29.26507	0.0011
HDT	10	875	23.51335	0.009
HGT	10	484	47.6425	<0.00001*
RML	10	466	30.8619	0.0006
RMLD	10	599	19.461	0.0348
UPL	10	470	20.693	0.0233
MC1L	10	524	16.9474	0.0755
SZSIA	9	370	16.5839	0.0556
OCAH	10	694	23.5034	0.009
FIST	10	959	18.3382	0.0495
FLE	10	622	22.2534	0.0139
FSIH	10	894	20.09	0.0284
TXNF	10	814	20.9143	0.0217
TINF	10	834	23.7681	0.0082
TMLP	10	488	23.6443	0.0086
CZB	10	599	22.1217	0.0145
CZH	10	691	19.9334	0.0299
Cranium	4	49	12.467	0.0142*
Cranium: Facial	6	119	12.8398	0.0457
Os coxae	4	46	10.0469	0.0396
Upper long bone lengths	9	203	17.4088	0.0427
Lower limb midshafts	10	698	21.4892*	0.0179
Hip	10	455	28.871	0.0013*

Table 5.18: Significant differences in directional asymmetry in adults from post-hoc tests between sites. (BF= Blackfriars, OCH=Chelsea, CH=Chichester, FG=Fishergate, HE=Hereford, HK=Hickleton, SH=St. Helen's, TO=Towton, WP=Wharram Percy, HCW=Wolverhampton, and YM=York Minster).

Measurement/Index	Differences are Between:	P
Measurement/Index	Differences are Between:	P
CMPL	BF and OCU	0.0004
	BF and FG	<0.00001
	BF and HE	0.0064
	BF and HK	0.0107
	BF and YM	0.0039
	OCU and WP	0.0163
	CH and FG	0.0038
	FG and SH	0.0167
	FG and WP	0.0002

Table 5.18: Continued.

Measurement/Index	Differences are Between:	P
CBZO	WP and YM	0.0026
CVML	HE and WP	0.044
SCL	CH and WP	0.0211
	FG and WP	0.0028
HXMS	BF and HCW	0.0167
	CH and HCW	0.0127
	HE and HCW	0.0182
	HK and HCW	0.0211
	SH and HCW	0.0044
	TO and HCW	0.0235
	WP and HCW	0.0024
HDT	CH and HCW	0.0383
	HE and HCW	0.048
	TO and HCW	0.0046
	WP and HCW	0.01272
HGT	OCU and CH	0.0021
	OCU and FG	0.0008
	OCU and HCW	0.0018
	CH and SH	0.0196
	FG and SH	0.0007
	FG and WP	0.0265
	SH and HCW	0.0351
RML	OCU and WP	0.0344
	WP and HCW	0.0215
MC1L	OCU and WP	0.0303
SZSIA	CH and WP	0.0194
FSIH	BF and OCU	0.0104
	BF and CH	0.0262
TXNF	CH and HE	0.0098
CZB	FG and HE	0.0348
CZH	FG and HE	0.0442
Cranium Facial	CH and WP	0.009
	WP and YM	0.463
Lower limb midshafts	CH and HE	0.0302
Hip	WP and HCW	0.0413

Subadults from specific sites possessed more variation in average median directional asymmetry than adults did from the same sites (see Table AP 6.9). Blackfriars had the highest average median DA score at 0.65% with a 95% confidence interval of -5.66 to 6.73% ($\overline{x}$ =0.53% and σ=3.1%), followed by Fishergate at 0.57% with a range of -5.65 to 6.77% ($\overline{x}$ =0.56% and σ=3.11%) and York Minster at 0.57% with a range of -5.35 to 6.31% ($\overline{x}$ =0.48% and σ=2.91%). Hickleton had the lowest average median DA score, with an almost symmetrical score of -0.01% and a range of -6.26 to 6.24% ($\overline{x}$ =-0.01%

and σ=3.12%). Hereford and Wharram Percy possessed the smallest range in population DA scores, while Wolverhampton and Chichester had the largest. Subadults from Hickleton and Wolverhampton had the highest number of measurements favouring the left side, both with 37, while Fishergate had the most favouring the right, with 56. Wharram Percy was found to have the most measurements favouring symmetry, with 24.

Kruskal-Wallis tests indicate that subadults had fewer measurements with significant differences in DA between sites than those from the adult population. Between site comparisons for subadults found 15 measurements and three indices with significant differences (see Tables 5.19 and AP 7.4). Of the measurements, two were in the skull, four in the upper limb and shoulder, two in the hand, one in the pelvic girdle, and six in the lower limb and foot. There were no differences in the clavicle, ulna, sacrum, or tarsals. Post-hoc tests indicate that of these overall significant differences, nine measurements and three indices had specific between site differences (see Tables 5.20, AP 7.8, and the electronic appendix). Chichester and Wharram Percy were found to have the most differences, with nine each, while Hickleton only had one difference. The majority of significant differences were between populations from Chichester and Wharram Percy. An additional difference was found between specific sites during post-hoc testing that was not uncovered during Kruskal-Wallis tests in URN between St. Helen's and York Minster.

Table 5.19: Significant results for directional asymmetry from Kruskal-Wallis ANOVA tests for between site comparisons for subadults. (*p significant after a Bonferroni adjustment).

Measurement	d	N	H	p-Value
CMPL	7	170	30.4159	0.0001*
MXRB	6	138	19.5667	0.0033
SGL	8	186	25.6521	0.0012
HSMLD	6	148	15.8859	0.0144
RXMS	7	268	15.2384	0.0325
URN	7	211	12.4854	0.0857
MC2L	4	67	11.6499	0.0202
MC4L	4	61	11.0623	0.0259
OCH	8	156	25.4601	0.0013
FML	8	197	15.9991	0.0424
FSIH	7	151	15.781	0.0272
TINF	8	272	20.5331	0.0085
MT1L	4	101	11.6943	0.0198
MT4L	4	54	12.9693	0.0114
MT5L	3	50	9.1611	0.0272
Upper limb midshafts	7	179	16.3149	0.0224
Lower limb midshafts	8	223	19.8255	0.011
Hip	6	111	13.378	0.0374

Table 5.20: Significant differences in directional asymmetry in subadults from post-hoc tests between sites. (CH=Chichester, FG=Fishergate, HE=Hereford, HK=Hickleton, SH=St. Helen's, WP=Wharram Percy, HCW=Wolverhampton, and YM=York Minster).

Measurement/Index	Differences are Between:	P
CMPL	BF and FG	0.036
	BF and HCW	0.043
	FG and WP	0.0104
	WP and HCW	0.0362
MXRB	FG and WP	0.0044
SGL	CH and SH	0.0053
	CH and WP	0.0058
HSMLD	CH and YM	0.0056
URN	SH and YM	0.0476
MC2L	HE and SH	0.0355
	HE and WP	0.0268
MC4L	CH and FG	0.0467
	CH and SH	0.0374
OCH	FG and WP	0.0014
	SH and WP	0.0056
FSIH	CH and WP	0.0466
MT4L	CH and FG	0.0044
	CH and WP	0.0409
Upper limb midshafts	HCW and YM	0.0204
Lower limb midshafts	HK and SH	0.0253
Hip	CH and HE	0.0395

5.5.5 Population Comparisons by Settlement Type

Average median directional asymmetry scores for adults compared by settlement type were the highest in the *leprosarium*/almshouse environment (see Table AP 6.10). Adults from Chichester's *leprosarium*/almshouse had an average median DA score of 0.43% with a 95% confidence interval of -5.97 to 6.93% ($\bar{x}$ =0.48% and σ=3.22%), followed by the rural environments at 0.37% with a range of -5.92 to 6.76% ($\bar{x}$ =0.42% and σ =3.17%). The urban settlements possessed the least directionality and lowest standard deviation, with a median of 0.35% and a range of -5.65 to 6.45% ($\bar{x}$ =0.4% and σ =3.03%). The *leprosarium*/almshouse also had the highest number of measurements with average medians favouring the right side, with 60 to the right, 20 to the left, and 21 favouring symmetry. Urban environments had 53 measurements to the right side, 15 to the left, and 33 symmetrical; while rural environments had 57 to the right, 20 to the left, and 24 symmetrical.

Kruskal-Wallis ANOVA tests for comparisons of the adult population based on settlement type indicate 23 measurements and three indices had significant differences (see Tables 5.21 and AP 7.3). Six of the measurements with significant differences were in the cranium, two from the shoulder, four from the upper limb and hand, five from the pelvic girdle, and six from the lower limb and foot. No significant differences in measurements were found in the mandible, hand, or tarsals. Post-hoc analysis indicates that of these measurements and indices significant differences were between specific sites for 19 measurements and three indices (see Tables 5.22, AP 7.9, and the electronic appendix). Rural environments had the most significant differences of all settlement types. Most of the significant differences occurred between *leprosarium*/almshouse and rural settlements, while urban and *leprosarium*/almshouses had the least. There was one further measurement and one index having specific between settlements differences observed during post-hoc testing. These were between urban and rural environments in MAL and between rural and *leprosarium*/almshouse settlements in midshaft measurements.

Table 5.21: Significant results for directional asymmetry from Kruskal-Wallis ANOVA tests for between settlement type comparisons for adults. (*p significant after a Bonferroni adjustment).

Measurement	D	N	H	p-Value
CFMTNS	2	231	6.1129	0.0448*
CMPL	2	720	6.8875	0.0319
CDGL	2	751	6.088	0.0476
COCL	2	533	10.2218	0.006
COPO	2	364	6.32053	0.0424
CBZO	2	213	11.435	0.0033
MAL	2	520	5.753	0.0563
CVWA	2	535	9.9187	0.007
SCL	2	209	12.8005	0.0017
HAPH	2	512	14.0525	0.0009
HGT	2	468	13.0167	0.0015
RMLD	2	584	7.4344	0.0243
UCH	2	525	7.353	0.0253
SZAB	2	538	7.5382	0.0231
SZSIA	2	370	10.9745	0.0041
OCIB	2	186	6.3116	0.0426
OCIS	2	416	6.0332	0.049
OCAH	2	683	12.0973	0.0024
FIST	2	932	6.2063	0.0449
FLE	2	601	6.8215	0.0330
TXNF	2	789	12.5321	0.0019
TINF	2	808	8.0277	0.0181
TLC	2	303	9.3105	0.0095
MT1L	2	538	7.5719	0.0227
Metatarsals	2	135	6.969	0.0307
Midshafts	2	356	5.891	0.0526
Lower limb midshafts	2	675	7.5784	0.0226
Knee	2	184	10.0938	0.0064

Table 5.22: Significant differences in directional asymmetry in adults from post-hoc tests between settlement types. (L/A=*leprosarium*/almshouse, R=rural, and U=urban).

Measurement/Index	Differences are Between:	P
CFMTNS	U and R	0.0385
CMPL	U and L/A	0.0434
COCL	R and L/A	0.0063
CBZO	U and R	0.0042
MAL	U and R	0.0496
CVWA	U and R	0.0077
SCL	U and R	0.0067
	R and L/A	0.0046
HAPH	U and R	0.0012
HGT	U and R	0.0384
	R and L/A	0.0038
RMLD	R and L/A	0.021
SZAB	R and U	0.0305
SZSIA	R and U	0.0113
	R and L/A	0.0089
OCIS	R and L/A	0.0487
OCAH	R and L/A	0.0015
FIST	U and L/A	0.0384
FLE	U and R	0.0322
TXNF	U and L/A	0.0012
TINF	R and L/A	0.0147
TLC	U and L/A	0.0087
MT1L	R and L/A	0.0214
Metatarsals	U and R	0.0249
Midshafts	R and L/A	0.0476
Lower limb midshafts	U and L/A	0.0206
Knee	U and R	0.0108
	R and L/A	0.0321

Similar to the adult population, the highest average median directional asymmetry for subadults was in the *leprosarium*/almshouse setting (see Table AP 6.11). The Chichester *leprosarium*/almshouse had an average median of 0.55% with a 95% confidence interval of -5.81 to 7.12% ($\bar{x}$ =0.65% and σ=3.23%). Urban and rural settlements were found to be similar, with an average urban DA median of 0.41% and a range of -5.8 to 6.57% ($\bar{x}$ =0.39% and σ=3.09%), and a rural median of 0.36% with a range of -5.25 to 6.05% ($\bar{x}$ =0.4% and σ=2.83%). The directionality of the measurements were similar for all settlement types, with urban environments having 48 to the right side, 17 to the left, and 20 favouring symmetry; rural environments with 42 to the right side, 20 to the left and 23 symmetrical; and the *leprosarium*/almshouse setting with 49 to the right side, 21 to the left and 15 symmetrical.

The Kruskal-Wallis ANOVA comparisons for subadults of differing settlement type indicate significant differences exist in 15 measurements and three indices (see Tables 5.23 and AP 7.4). Of these measurements, three were in the skull, two in the upper limb and shoulder, two in the hand, two in the pelvic girdle, and six in the lower limb and foot. Post-hoc tests indicate that fifteen measurements and three indices had significant differences between specific settlement types (see Tables 5.24, AP 7.10, and the electronic appendix). Rural settlements had the most between site differences, with the majority of differences between the *leprosarium*/almshouse and rural environments.

Table 5.23: Significant results for directional asymmetry from Kruskal-Wallis ANOVA tests for between settlement type comparisons for subadults. (*p significant after a Bonferroni adjustment).

Measurement	d	N	H	p-Value
CMAH	2	141	6.5056	0.0387
CMPL	2	174	14.5623	0.0007*
MXRB	2	144	12.4551	0.002
SGL	2	188	14.1638	0.0008
HSMLD	2	157	11.967	0.0025
RXMS	2	273	9.5701	0.0084
MC4L	2	70	11.3038	0.0035
SZAB	2	140	6.7951	0.0335
OCH	2	158	15.9052	0.0004*
FEB	2	75	6.0882	0.0476
FSIH	2	153	14.8467	0.0006*
TINF	2	275	15.3226	0.0005*
MT1L	2	111	8.5409	0.014
MT4L	2	59	6.2363	0.0442
MT5L	2	56	8.6583	0.0132
Pelvic girdle	1	27	4.4471	0.035
Lower limb midshafts	2	224	9.4547	0.0089
Hip	2	116	9.2073	0.01

Table 5.24: Significant differences in directional asymmetry in subadults from post-hoc tests between settlement types. (L/A=*leprosarium*/almshouse, R=rural, and U=urban).

Measurement/Index	Differences are Between:	P
CMAH	U and R	0.0039
CMPL	L/A and R	0.0082
	U and R	0.0023
MXRB	U and R	0.0013
SGL	L/A and U	0.0037
	L/A and R	0.0005
HSMLD	L/A and U	0.0022
	L/A and R	0.0251
RXMS	L/A and R	0.006
MC4L	L/A and U	0.0027
SZAB	L/A and U	0.0039
OCH	U and R	0.0003
FEB	L/A and U	0.0415
FSIH	L/A and R	0.0013
	U and R	0.0152
TINF	L/A and R	0.0011
	U and R	0.0066
MT1L	L/A and R	0.0113
MT4L	L/A and U	0.444
MT5L	L/A and R	0.0189
Pelvic girdle	U and R	0.035
Lower limb midshafts	L/A and R	0.0471
	U and R	0.0151
Hip	L/A and U	0.0188
	L/A and R	0.0077

5.5.6 Population Comparisons by Period

There was a gradual diachronic rise in average median adult directional asymmetry levels (see Table AP 6.12). The post-Medieval period had a slightly higher average DA median at 0.42% with a 95% confidence interval of -6.48 to 7.33% ($\overline{x}$ =0.42% and σ =3.07%), followed by the Medieval period at 0.38% with a range of -5.72 to -6.57% ($\overline{x}$ =0.42% and σ=3.07%), and then the Anglo-Saxon period with the lowest median at 0.35% and a range of -5.48 to 6.17% ($\overline{x}$ =o.34% and σ=2.91%). The Anglo-Saxon period had the most measurements with average medians favouring the left side, with 24 to the left, 52 to the right, and 25 favouring symmetry. Medieval and post-medieval sites were found to be similar, with medieval sites having 59 measurements to the right side, 14 to the left, and 28 favouring symmetry, while post-medieval sites had 58 to the right side, 15 to the left, and 28 symmetrical.

Kruskal-Wallis ANOVA tests for comparisons of the adult population based on period found eight measurements and two indices with significant differences (see Tables 5.25 and AP 7.3). Four of the measurements with significant differences were from the skull, one from the clavicle, two in the humerus, and one in the ulna. Post-hoc analysis indicates that of these measurements and indices, significant differences were between specific sites for all eight measurements and one index (see Tables 5.26, AP 7.11, and the electronic appendix). The majority of significant differences were between the Anglo-Saxon populations and the Medieval and post-Medieval periods, with the most common differences between Anglo-Saxon and medieval sites. The least number of differences occurred between the Medieval and the post-Medieval periods.

Table 5.25: Significant results for directional asymmetry from Kruskal-Wallis ANOVA tests for between period comparisons for adults. (*p significant after a Bonferroni adjustment).

Measurement	D	N	H	p-Value
CMPL	2	671	11.0741	0.0039
CBPO	2	347	8.3512	0.0154
CBAST	2	426	10.1959	0.0061
MIRB	2	639	7.4711	0.0239
CVWS	2	448	6.2352	0.0443
HML	2	497	16.3638	0.0003*
HGT	2	438	7.41	0.0246
URN	2	678	7.9036	0.0192
Tarsals	2	377	7.5218	0.0233
Knee	2	177	6.0194	0.0493

Table 5.26: Significant differences in directional asymmetry in adults from post-hoc tests between periods. (AS=Anglo-Saxon, M=Medieval, PM=post-Medieval).

Measurement/Index	Differences are Between:	P
CMPL	M and PM	0.0264
	AS and M	0.0446
CBPO	AS and M	0.0328
	AS and PM	0.0279
CBAST	AS and M	0.0119
MIRB	AS and PM	0.0191
CVWA	AS and M	0.0376
HML	M and PM	0.0032
	AS and M	0.0168
HGT	M and PM	0.0463
URN	AS and PM	0.0155
Tarsals	AS and PM	0.0257

Similar to adults, there was a diachronic increase in average median directional asymmetry scores for subadults, although there was greater variation in subadult scores than in the corresponding adult groups (see Tables AP 6.12-13). The post-Medieval period had the highest median DA scores at 0.59% and a 95% confidence interval of -6.06 to 7.14% ($\overline{x}$ =0.54% and σ=3.30%), followed by the Medieval period at 0.39% with a range of -5.76 to 6.58% ($\overline{x}$ =0.41% and σ=3.09%), and then individuals from the Anglo-Saxon period at 0.24% with a range of -5.64 to 6.20% ($\overline{x}$ =0.28% and σ =2.96%). Similar to adults, subadults from the Anglo-Saxon period had the most measurements with average medians favouring the left side, with 30 to the left, 44 to the right and 11 favouring symmetry. The medieval population had 48 to the right side, 16 to the left, and 21 symmetrical, while the post-Medieval period had 47 to the right side, 24 to the left, and 13 favouring symmetry.

Only three significant differences were found during Kruskal-Wallis ANOVA and post-hoc comparisons for the subadult population from different periods (see Tables 5.27 and AP 7.4). Post-hoc tests indicate these differences occurred in SAL between the Anglo-Saxon and Medieval periods, RIMS between the Medieval and post-Medieval periods, and in the scapular index between the Anglo-Saxon and post-Medieval periods (see Tables 5.28, AP 7.12, and the electronic appendix).

Table 5.27: Significant results for directional asymmetry from Kruskal-Wallis ANOVA tests for between period comparisons for subadults. (*p significant after a Bonferroni adjustment).

Measurement	d	N	H	p-Value
SAL	2	56	5.9926	0.05
RIMS	2	195	8.5825	0.0137
Scapula	2	45	8.0281	0.0181

Table 5.28: Significant differences in directional asymmetry in subadults from post-hoc tests between periods. (AS=Anglo-Saxon, M=Medieval, PM=post-Medieval).

Measurement/Index	Differences are Between:	P
SAL	AS and M	0.0432
RIMS	M and PM	0.0411
Scapula	AS and PM	0.0222

5.5.7 Significance of and Effects of Directional Asymmetry on Interpreting Fluctuating Asymmetry Data

One-sample t-tests of mean (R-L) differences indicate that of the 103 adult measurements, 76 exhibited significant directional asymmetry (see Table 5.29). Eight traits in the cranium were not significantly directional, which were mainly located in the viscerocranium and basicranium. All traits in the mandible and clavicle were significantly directional, apart from MXRB and CVLC. All traits of the scapula, humerus, radius, ulna, and metacarpals were found to be significantly directional. The only significantly directional trait in the sacrum was SZAPA, while the *os coxae* had four significant and three non-significant traits. For the femur and tibia only FIMS, FMLP, TLM, and TXNF were non significant. Lastly, all traits of the tarsals and metatarsals were significantly directional except for CZL, TZB, MC3L and MC4 length.

Comparatively fewer subadult measurements were significantly directional than those of the adults. Of the 85 subadult measurements, 41 were found to be significantly directional (see Table 5.30). The cranium only had four traits that were not significantly directional, CFMT, CFMTB, CDGL, and COCL. Of the mandibular traits, only MHR was found to be significantly directional. All traits of the scapula, humerus, radius, and ulna were significantly directional, apart from CVMC and CVLC, SGB, RGH, RMLD. Unlike the adults, none of the metacarpal lengths for subadults were significantly directional. The only significantly directional traits in the pelvis were SZAB and OCIB. For the femur and tibia only FML, FIMS, FXST, FIST, FMLP and TINF were significant. Lastly, all traits of the tarsals and metatarsals were not significantly directional, except for MT3L.

Although many measurements express significant DA, comparisons of mean (R-L) to FA4a for all adult and subadult measurements indicates that the deviation about mean (R-L) was larger than mean (R-L). Therefore, all measurements that exhibited DA, although significant, could be due to deviations about the mean due mainly to developmental instability (Palmer and Strobeck 2003), and were thus included in the analysis of fluctuating asymmetry.

Table 5.29: Adult one sample t-tests evaluating the significance of directional asymmetry and a comparison of mean (R-L) and FA4a. (*p<0.05; **p remains significant after a Bonferroni adjustment).

Measurement	N	t-Value	p-Value	Mean (R-L)	FA4a**
COBB	223	4.4663	<0.00001**	0.2027	0.5408
COBH	230	-0.7337	0.4639	-0.0361	0.5952
CNOR	222	0.3467	0.7292	0.0167	0.5716
CFMTN	598	5.1021	<0.00001**	0.146	0.5584
CFMTNS	231	-0.0457	0.9636	-0.0035	0.9188
CMAH	637	0.3423	0.7322	0.0119	0.702
CECMIS	363	0.7852	0.4328	0.0366	0.7094
CFMTB	504	5.4642	<0.00001**	0.3726	1.2217
CBZO	213	8.8809	<0.00001**	0.8052	1.0559
CMPL	736	5.6027	<0.00001**	0.2497	0.965
CMPB	806	5.0372	<0.00001**	0.1682	0.7567
CMPH	695	0.1646	0.8693	0.0091	1.1582
CMSAST	691	5.0374	<0.00001**	0.3411	1.4204
CDGL	762	-2.8671	0.0043*	-0.2424	1.8623
COCL	538	-0.0402	0.9679	-0.0024	1.1126
COPO	365	-1.5044	0.1334	-0.1151	1.1661
CBAPO	342	-2.9043	0.0039*	-0.2386	1.2124
CNMS	325	3.8094	0.0002**	0.2954	1.1155
CBPO	386	5.2998	<0.00001**	0.5531	1.6363
CBAST	474	6.7116	<0.00001**	0.612	1.5843
CLFMT	418	5.0089	<0.00001**	0.3589	1.1689
CLAST	478	4.0935	<0.00001**	0.3603	1.5354
MAL	528	-2.5173	0.0121*	-0.1773	1.2913
MRH	529	3.7554	0.0002**	0.2261	1.105
MXRB	389	1.4965	0.1353	0.1144	1.2031
MIRB	710	-4.6608	<0.00001**	-0.197	0.8989
CVML	484	-10.9648	<0.00001**	-1.6519	2.6448
CVXMS	860	6.8726	<0.00001**	0.1881	0.6406
CVIMS	867	-2.2097	0.0274*	-0.0561	0.5961
CVWA	550	5.3302	<0.00001**	0.3744	1.3144
CVWS	507	6.5602	<0.00001**	0.4335	1.1874
CVMC	465	-3.6213	0.0003**	-0.2998	1.4245
CVLC	452	1.5736	0.1163	0.1235	1.331
SGL	505	8.2660	<0.00001**	0.3497	0.7587
SGB	511	3.1651	0.0016*	0.1247	0.7105
SAL	227	5.0897	<0.00001**	0.6476	1.5297
SCL	216	4.7682	<0.00001**	0.381	0.9372
HML	552	21.4160	<0.00001**	3.269	2.8619
HXMS	895	18.9586	<0.00001**	0.5463	0.6879
HIMS	890	11.9649	<0.00001**	0.2818	0.5607
HDT	875	15.6700	<0.00001**	0.488	0.7351
HSIH	633	8.5464	<0.00001**	0.3442	0.8087
HAPH	526	13.4270	<0.00001**	0.6093	0.8305
HEB	674	13.0132	<0.00001**	0.5878	0.9358
HGT	484	15.2204	<0.00001**	0.7298	0.8417
RML	466	12.3957	<0.00001**	1.5236	2.1174
RXMS	850	16.6881	<0.00001**	0.4701	0.6554
RIMS	853	6.2834	<0.00001**	0.1213	0.4501
RGH	356	4.1160	<0.00001**	0.1261	0.4614
RMLD	599	8.0442	<0.00001**	0.2644	0.642
UML	364	11.1098	<0.00001**	1.7266	2.3662

Table 5.29: Continued.

Measurement	N	t-Value	p-Value	Mean (R-L)	FA4a**
UPL	470	12.0554	<0.00001**	1.6947	2.432
UXMS	800	9.9683	<0.00001**	0.3349	0.7582
UIMS	812	10.2689	<0.00001**	0.3059	0.6774
URN	749	8.8102	<0.00001**	0.333	0.8254
UOW	697	5.7628	<0.00001**	0.2007	0.7338
UCH	540	5.7750	<0.00001**	0.2915	0.936
MC1L	524	7.2852	<0.00001**	0.229	0.5742
MC2L	541	5.5300	<0.00001**	0.1946	0.6533
MC3L	524	3.5930	0.0004**	0.1536	0.7811
MC4L	502	5.1403	<0.00001**	0.197	0.6853
MC5L	445	4.1344	<0.00001**	0.1901	0.7741
SZAB	548	-1.5032	0.1334	-0.1438	1.787
SZAW	386	-0.8358	0.4038	-0.0995	1.8662
SZAPA	454	3.3959	0.0007**	0.3976	1.9906
SZSIA	372	1.7734	0.0770	0.2202	1.9108
SZS1	648	-1.3439	0.1795	-0.0588	0.8888
OCH	275	-4.0727	0.0001**	-0.4182	1.3588
OCIB	186	0.1508	0.8803	0.0237	1.7078
OCPL	166	-0.8638	0.3889	-0.0837	0.9966
OCIS	421	3.1236	0.0019*	0.1777	0.9313
OCAH	694	5.4356	<0.00001**	0.2003	0.7746
OCASH	811	3.7535	0.0002**	0.338	2.0463
OCASB	489	1.9073	0.0571	0.2515	2.3272
FML	695	-6.0207	<0.00001**	-0.9072	3.1699
FXMS	933	-2.3297	0.02*	-0.08	0.8366
FIMS	931	-1.0900	0.2760	-0.0293	0.6551
FXST	948	-2.8568	0.0044*	-0.12	1.0324
FIST	959	2.0088	0.0448*	0.0686	0.8441
FEB	624	7.1858	<0.00001**	0.3133	0.8691
FLE	622	5.3646	<0.00001**	0.2371	0.8798
FAPH	866	6.5921	<0.00001**	0.1712	0.61
FSIH	894	3.1361	0.0018*	0.0883	0.6715
FMLP	747	-0.4516	0.6517	-0.0266	1.2865
TML	576	-1.7589	0.0791	-0.2243	2.4423
TXNF	814	-1.1274	0.2599	-0.0448	0.9056
TINF	834	8.0814	<0.00001**	0.2658	0.7581
TMLP	488	5.0444	<0.00001**	0.2238	0.782
TMC	318	1.9741	0.0492*	0.1164	0.8387
TLC	324	2.9978	0.0029*	0.159	0.7616
CZL	661	0.2692	0.7878	0.0106	0.807
CZB	599	-5.6950	<0.00001**	-0.2304	0.7901
CZH	691	2.3786	0.0176*	0.0897	0.7913
TZL	630	-2.7678	0.0058*	-0.1127	0.8156
TZB	646	-0.6392	0.5229	-0.0248	0.7859
TZH	660	-2.1639	0.0308*	-0.0621	0.5885
MT1L	556	-5.9452	<0.00001**	-0.223	0.7059
MT2L	347	1.9820	0.0483*	0.0994	0.7457
MT3L	364	0.7355	0.4625	0.0321	0.6654
MT4L	356	1.9381	0.0534	0.1028	0.7987
MT5L	378	2.4254	0.0158*	0.1489	0.9527

**FA4a=0.798√Var(R-L)

Table 5.30: Subadult one-sample t-tests evaluating the significance of directional asymmetry and a comparison of mean (R-L) and FA4a. (*p<0.05**p remains significant after a Bonferroni adjustment).

Measurement	N	t-Value	p-Value	Mean (R-L)	FA4a**
CFMTN	115	0.3813	0.7037	0.0243	0.5464
CMAH	141	-3.0053	0.0031*	-0.166	0.5233
CECMIS	120	-2.2487	0.0264*	-0.1025	0.3985
CFMTB	45	1.1843	0.2427	0.3644	1.6473
CMPL	174	7.6496	<0.00001**	0.6115	0.8415
CMPB	174	2.8636	0.0047*	0.2034	0.7478
CMSAST	132	2.9325	0.004*	0.447	1.3974
CDGL	136	-1.1100	0.2690	-0.1676	1.4055
COCL	168	0.3077	0.7587	0.019	0.6402
MAL	162	1.6982	0.0914	0.1521	0.8877
MRH	175	3.1019	0.0022*	0.1869	0.6286
MXRB	143	0.7942	0.4284	0.0674	0.8038
MIRB	216	-1.9663	0.0506	-0.1129	0.675
CVML	143	-2.8249	0.0054*	-0.4188	1.3986
CVXMS	278	2.3696	0.0185*	0.0724	0.4094
CVWA	158	4.0504	0.0001**	0.2887	0.7397
CVWS	155	4.2474	<0.00001**	0.3128	0.7343
CVMC	70	0.1611	0.8725	0.02	0.8287
CVLC	64	0.4012	0.6896	0.0594	0.9447
SGL	187	5.3810	<0.00001**	0.2766	0.5667
SGB	189	-1.2079	0.2286	-0.0547	0.4707
SAL	74	5.5252	<0.00001**	0.348	0.454
HML	194	6.9257	<0.00001**	1.1159	1.8009
HXMS	299	7.2058	<0.00001**	0.1993	0.3832
HIMS	298	3.5295	0.0005**	0.0977	0.3805
HDT	250	7.6681	<0.00001**	0.2696	0.4436
HSIH	79	3.0396	0.0032*	0.2873	0.6705
HAPH	72	2.4707	0.0159*	0.2486	0.6814
HSMLD	156	5.7745	<0.00001**	0.3522	0.6055
HSMLP	155	5.2848	<0.00001**	0.2955	0.5657
HGT	42	3.4596	0.0013*	0.4	0.5979
RML	123	5.5363	<0.00001**	0.7089	1.1389
RXMS	272	7.3252	<0.00001**	0.2051	0.3686
RIMS	268	3.5436	0.0005**	0.0788	0.286
RGH	117	1.6964	0.0925	0.072	0.3681
RSMLD	84	4.9400	<0.00001**	0.2541	0.384
RMLD	31	1.8412	0.0755	0.2032	0.4904
UML	109	3.9519	0.0001**	0.6245	1.3171
UPL	105	3.3630	0.0011*	0.5933	1.4427
UXMS	260	2.7558	0.0063*	0.0866	0.4051
UIMS	266	5.2629	<0.00001**	0.1727	0.4242
URN	214	2.6716	0.0081*	0.1535	0.6552
UOW	219	4.4420	<0.00001**	0.1845	0.4961
UCH	199	3.1024	0.0022*	0.133	0.4839
MC1L	60	0.6602	0.5117	0.055	0.515
MC2L	77	1.2806	0.2042	0.1065	0.5823
MC3L	74	1.2864	0.2024	0.0986	0.5264
MC4L	70	0.1374	0.8911	0.01	0.4859
MC5L	48	1.8828	0.0659	0.1354	0.3976
SZAB	140	0.2924	0.7704	0.02	0.6459
SZS1	157	4.8631	<0.00001**	0.2516	0.5173

Table 5.30: Continued.

Measurement	N	t-Value	p-Value	Mean (R-L)	FA4a**
OCH	157	-0.2120	0.8324	-0.0203	0.809
OCIB	114	3.7831	0.0002**	0.3861	0.8784
OCIS	179	1.4260	0.1556	0.0733	0.5506
OCASH	305	0.0515	0.9589	0.0039	1.3277
OCASB	210	1.0609	0.2900	0.0929	1.0414
FML	197	-3.5543	0.0005**	-0.5424	1.704
FXMS	294	0.4092	0.6827	0.0115	0.4435
FIMS	298	-2.9321	0.0036*	-0.0846	0.3951
FXST	311	-2.6180	0.0093*	-0.1359	0.7299
FIST	315	2.6592	0.0082*	0.1275	0.6821
FSMLD	109	-0.2434	0.8081	-0.0173	0.7828
FEB	75	0.6273	0.5324	0.0547	0.6022
FLE	122	0.3890	0.6980	0.0311	0.7058
FAPH	162	0.9501	0.3435	0.0512	0.5477
FSIH	153	0.0385	0.9694	0.002	0.5032
FMLP	254	-2.2449	0.0256*	-0.1251	0.7171
TML	173	-0.6999	0.4849	-0.096	1.4696
TXNF	275	0.4536	0.6505	0.0196	0.6038
TINF	274	2.5526	0.0112*	0.1033	0.523
TSMLP	86	1.6646	0.0997	0.1529	0.6836
TMLP	89	0.3633	0.7173	0.027	0.5588
TMC	52	1.4741	0.1466	0.1577	0.6156
TLC	55	-0.7873	0.4346	-0.0709	0.533
CZL	121	-1.6797	0.0956	-0.1066	0.5571
CZB	102	-0.4891	0.6259	-0.0324	0.5332
CZH	103	1.7604	0.0813	0.1301	0.5985
TZL	106	0.1909	0.8490	0.0132	0.5683
TZB	97	-0.7861	0.4337	-0.0588	0.5875
TZH	107	0.3081	0.7586	0.0187	0.5008
MT1L	111	0.1701	0.8653	0.0099	0.4899
MT2L	69	-0.4903	0.6255	-0.0435	0.5878
MT3L	62	2.0886	0.0409*	0.1532	0.461
MT4L	59	-1.3985	0.1673	-0.1186	0.52
MT5L	56	0.2674	0.7902	0.0286	0.6382

**FA4a=0.798√Var(R-L)

5.6 Fluctuating asymmetry

5.6.1 Descriptive Statistics

The average median fluctuating asymmetry for all adult measurements was 1.99%, with a 95% confidence interval of between 0 to 6.53% ($\bar{x}$ =2.46% and σ=2.04%) (see Table 5.31) The measurements with the highest median FA were CVLC (9.06%), CMPH (8.7%), CDGL (5.94%), CVMC (5.81%), and CVIMS (4.76%). Only three measurements had an average median of zero, including CFMTB, CNMS, and TZH.

Those measurements with the highest standard deviation, and thus the greatest range include CMPH ($\bar{x}$ =11.7% and σ=10.03%), CVLC ($\bar{x}$ =10.66% and σ=7.96%), CDGL ($\bar{x}$ =7.81% and σ=6.63%), CVMC ($\bar{x}$ =7.21% and σ=5.61%), and SZAB ($\bar{x}$ =5.57% and σ=4.67%). Those with the lowest standard deviation, and thus the most stable measurements, include OCH ($\bar{x}$ =0.58% and σ=0.56%), TML ($\bar{x}$ =0.55% and σ =0.56%), FML ($\bar{x}$ =0.63% and σ=0.58%), OCIS ($\bar{x}$ =0.59% and σ=0.64%), and CLFMT ($\bar{x}$ =0.59% and σ=0.71%). Indices with the highest median include the clavicle (5.52%), temporal bone of the cranium (5.05%), and upper limb midshafts (4.14%); while those with the lowest medians include lower long bone lengths (0.62%), cranial vault (0.91%), and upper long bone lengths (1.01%). Those indices with the highest range were the temporal bone of the cranium ($\bar{x}$ =5.61% and σ=2.94%), the sacro-iliac joint ($\bar{x}$ =4.05% and σ=2.2%), and the clavicle ($\bar{x}$ =5.52% and σ=2.2%). The most stable indices include long bone lengths ($\bar{x}$ =0.62% and σ=0.43%), metatarsals ($\bar{x}$ =1.02% and σ=0.46%), and metacarpals ($\bar{x}$ =1.17% and σ=0.47%).

Table 5.31: Fluctuating asymmetry descriptive results for adults.

Measurement	N	Median	Mean	Minimum	Maximum	Std. Dev.	Confidence interval 95%
COBB	223	0.0126	0.0145	0.0000	0.0525	0.0112	0 to 3.69%
COBH	230	0.0156	0.0178	0.0000	0.0638	0.0132	0 to 4.42%
CNOR	222	0.0096	0.0106	0.0000	0.0347	0.0075	0 to 2.56%
CFMTN	598	0.0077	0.0099	0.0000	0.0414	0.0081	0 to 2.61%
CFMTNS	231	0.0080	0.0113	0.0000	0.0614	0.0102	0 to 3.17%
CMAH	637	0.0239	0.0295	0.0000	0.1252	0.0243	0 to 7.81%
CECMIS	363	0.0157	0.0215	0.0000	0.0977	0.0197	0 to 6.09%
CFMTB	504	0.0000	0.0081	0.0000	0.0509	0.0113	0 to 3.07%
CBZO	213	0.0072	0.0071	0.0000	0.0383	0.0092	0 to 2.55%
CMPL	736	0.0215	0.0294	0.0000	0.1362	0.0269	0 to 8.32%
CMPB	806	0.0198	0.0269	0.0000	0.1244	0.0244	0 to 7.57%
CMPH	695	0.0870	0.1170	0.0000	0.5108	0.1003	0 to 31.76%
CMSAST	691	0.0228	0.0292	0.0000	0.1100	0.0231	0 to 7.54%
CDGL	762	0.0594	0.0781	0.0000	0.3330	0.0663	0 to 21.07%
COCL	538	0.0290	0.0404	0.0000	0.1803	0.0374	0 to 11.52%
COPO	365	0.0094	0.0145	0.0000	0.0649	0.0143	0 to 4.31%
CBAPO	342	0.0123	0.0180	0.0000	0.0822	0.0173	0 to 5.26%
CNMS	325	0.0000	0.0069	0.0000	0.0415	0.0093	0 to 2.55%
CBPO	386	0.0080	0.0113	0.0000	0.0591	0.0127	0 to 3.67%

Table 5.31: Continued.

Measurement	N	Median	Mean	Minimum	Maximum	Std. Dev.	Confidence interval 95%
CBAST	474	0.0074	0.0105	0.0000	0.0513	0.0112	0 to 3.29%
CLFMT	418	0.0059	0.0059	0.0000	0.0317	0.0071	0 to 2.01%
CLAST	478	0.0106	0.0159	0.0000	0.0695	0.0152	0 to 4.63%
MAL	528	0.0060	0.0095	0.0000	0.0442	0.0092	0 to 2.79%
MRH	529	0.0107	0.0152	0.0000	0.0693	0.0140	0 to 4.32%
MXRB	389	0.0226	0.0273	0.0000	0.1102	0.0217	0 to 7.07%
MIRB	710	0.0246	0.0297	0.0000	0.1082	0.0221	0 to 7.39%
CVML	484	0.0161	0.0203	0.0000	0.0785	0.0158	0 to 5.19%
CVXMS	860	0.0394	0.0481	0.0000	0.1907	0.0373	0 to 12.27%
CVIMS	867	0.0476	0.0595	0.0000	0.2208	0.0457	0 to 15.09%
CVWA	550	0.0410	0.0531	0.0000	0.2124	0.0437	0 to 14.05%
CVWS	507	0.0367	0.0448	0.0000	0.1740	0.0361	0 to 11.7%
CVMC	465	0.0581	0.0721	0.0000	0.2683	0.0561	0 to 18.43%
CVLC	452	0.0906	0.1068	0.0000	0.4112	0.0796	0 to 26.6%
SGL	505	0.0161	0.0199	0.0000	0.0756	0.0158	0 to 5.15%
SGB	511	0.0220	0.0251	0.0000	0.1001	0.0191	0 to 6.33%
SAL	227	0.0194	0.0308	0.0000	0.1390	0.0305	0 to 9.18%
SCL	216	0.0181	0.0213	0.0000	0.0741	0.0164	0 to 5.41%
HML	552	0.0111	0.0125	0.0000	0.0440	0.0090	0 to 3.05%
HXMS	895	0.0297	0.0353	0.0000	0.1421	0.0266	0 to 8.85%
HIMS	890	0.0306	0.0333	0.0000	0.1224	0.0240	0 to 8.13%
HDT	875	0.0301	0.0351	0.0000	0.1324	0.0263	0 to 8.77%
HSIH	633	0.0162	0.0188	0.0000	0.0749	0.0144	0 to 4.76%
HAPH	526	0.0188	0.0222	0.0000	0.0859	0.0170	0 to 5.62%
HEB	674	0.0146	0.0169	0.0000	0.0665	0.0128	0 to 4.25%
HGT	484	0.0226	0.0271	0.0000	0.0992	0.0206	0 to 6.83%
RML	466	0.0087	0.0103	0.0000	0.0384	0.0082	0 to 2.67%
RXMS	850	0.0381	0.0458	0.0000	0.1846	0.0352	0 to 11.62%
RIMS	853	0.0315	0.0388	0.0000	0.1593	0.0302	0 to 9.92%
RGH	356	0.0166	0.0203	0.0000	0.0794	0.0164	0 to 5.31%
RMLD	599	0.0161	0.0199	0.0000	0.0815	0.0159	0 to 5.17%
UML	364	0.0085	0.0108	0.0000	0.0418	0.0084	0 to 2.76%
UPL	470	0.0095	0.0120	0.0000	0.0488	0.0098	0 to 3.16%
UXMS	800	0.0398	0.0462	0.0000	0.1741	0.0349	0 to 11.6%
UIMS	812	0.0455	0.0536	0.0000	0.2052	0.0419	0 to 13.74%
URN	749	0.0190	0.0232	0.0000	0.0946	0.0180	0 to 5.92%
UOW	697	0.0255	0.0292	0.0000	0.1070	0.0220	0 to 7.32%
UCH	540	0.0220	0.0257	0.0000	0.1038	0.0203	0 to 6.63%
MC1L	524	0.0111	0.0134	0.0000	0.0528	0.0100	0 to 3.34%
MC2L	541	0.0084	0.0099	0.0000	0.0363	0.0074	0 to 2.47%
MC3L	524	0.0099	0.0118	0.0000	0.0424	0.0091	0 to 3%
MC4L	502	0.0103	0.0121	0.0000	0.0480	0.0095	0 to 3.11%
MC5L	445	0.0125	0.0147	0.0000	0.0524	0.0109	0 to 3.65%
SZAB	548	0.0438	0.0557	0.0000	0.2323	0.0467	0 to 14.91%
SZAW	386	0.0227	0.0306	0.0000	0.1227	0.0268	0 to 8.42%
SZAPA	454	0.0377	0.0480	0.0000	0.1963	0.0391	0 to 12.62%
SZSIA	372	0.0216	0.0291	0.0000	0.1160	0.0243	0 to 7.77%
SZS1	648	0.0268	0.0340	0.0000	0.1431	0.0281	0 to 9.02%
OCH	275	0.0046	0.0058	0.0000	0.0256	0.0056	0 to 1.7%
OCIB	186	0.0067	0.0104	0.0000	0.0397	0.0082	0 to 2.68%
OCPL	166	0.0115	0.0137	0.0000	0.0475	0.0098	0 to 3.33%

Table 5.31: Continued.

Measurement	N	Median	Mean	Minimum	Maximum	Std. Dev.	Confidence interval 95%
OCIS	421	0.0059	0.0080	0.0000	0.0324	0.0064	0 to 2.08%
OCAH	694	0.0112	0.0148	0.0000	0.0622	0.0122	0 to 3.92%
OCASH	811	0.0360	0.0471	0.0000	0.2102	0.0391	0 to 12.53%
OCASB	489	0.0258	0.0366	0.0000	0.1694	0.0349	0 to 10.64%
FML	695	0.0063	0.0072	0.0000	0.0299	0.0058	0 to 1.88%
FXMS	933	0.0231	0.0279	0.0000	0.1105	0.0217	0 to 7.13%
FIMS	931	0.0198	0.0248	0.0000	0.1089	0.0211	0 to 6.7%
FXST	948	0.0235	0.0284	0.0000	0.1307	0.0224	0 to 7.32%
FIST	959	0.0250	0.0303	0.0000	0.1239	0.0239	0 to 7.81%
FEB	624	0.0116	0.0098	0.0000	0.0715	0.0101	0 to 3%
FLE	622	0.0153	0.0133	0.0000	0.0616	0.0125	0 to 3.83%
FAPH	866	0.0106	0.0132	0.0000	0.0562	0.0107	0 to 3.46%
FSIH	894	0.0116	0.0142	0.0000	0.0524	0.0110	0 to 3.62%
FMLP	747	0.0105	0.0129	0.0000	0.0518	0.0107	0 to 3.43%
TML	576	0.0055	0.0066	0.0000	0.0282	0.0056	0 to 1.78%
TXNF	814	0.0213	0.0262	0.0000	0.1038	0.0205	0 to 6.72%
TINF	834	0.0263	0.0324	0.0000	0.1318	0.0259	0 to 8.42%
TMLP	488	0.0124	0.0096	0.0000	0.0445	0.0096	0 to 2.88%
TMC	318	0.0139	0.0171	0.0000	0.0688	0.0142	0 to 4.55%
TLC	324	0.0147	0.0184	0.0000	0.0715	0.0147	0 to 4.78%
CZL	661	0.0114	0.0084	0.0000	0.0500	0.0097	0 to 2.78%
CZB	599	0.0211	0.0156	0.0000	0.0852	0.0173	0 to 5.02%
CZH	691	0.0202	0.0155	0.0000	0.0690	0.0151	0 to 4.57%
TZL	630	0.0163	0.0124	0.0000	0.0715	0.0131	0 to 3.86%
TZB	646	0.0220	0.0160	0.0000	0.0800	0.0170	0 to 5%
TZH	660	0.0000	0.0147	0.0000	0.0667	0.0172	0 to 4.91%
MT1L	556	0.0085	0.0111	0.0000	0.0472	0.0093	0 to 2.97%
MT2L	347	0.0083	0.0099	0.0000	0.0349	0.0077	0 to 2.53%
MT3L	364	0.0078	0.0094	0.0000	0.0369	0.0075	0 to 2.44%
MT4L	356	0.0093	0.0113	0.0000	0.0441	0.0093	0 to 2.99%
MT5L	378	0.0113	0.0137	0.0000	0.0462	0.0102	0 to 3.41%
Cranium	57	0.0234	0.0237	0.0115	0.0412	0.0082	0 to 4.01%
Cranium: Orbit	202	0.0125	0.0142	0.0000	0.0420	0.0069	0 to 2.8%
Cranium: Facial	125	0.0143	0.0149	0.0017	0.0385	0.0071	0 to 2.91%
Cranium: Temporal	546	0.0505	0.0561	0.0032	0.2001	0.0294	0 to 11.49%
Cranium: Base	215	0.0170	0.0201	0.0016	0.0588	0.0125	0 to 4.51%
Cranium: Vault	328	0.0091	0.0111	0.0000	0.0381	0.0079	0 to 2.69%
Mandible	306	0.0181	0.0204	0.0024	0.0707	0.0111	0 to 4.26%
Clavicle	270	0.0552	0.0568	0.0123	0.1227	0.0202	0 to 9.72%
Scapula	65	0.0238	0.0236	0.0015	0.0604	0.0122	0 to 4.8%
Humerus	305	0.0234	0.0249	0.0076	0.0594	0.0090	0 to 4.29%
Radius	229	0.0248	0.0263	0.0052	0.0674	0.0114	0 to 4.91%
Ulna	212	0.0279	0.0287	0.0089	0.0659	0.0115	0 to 5.17%
Metacarpals	154	0.0117	0.0124	0.0035	0.0311	0.0047	0 to 2.18%
Pelvic girdle	35	0.0262	0.0268	0.0131	0.0492	0.0092	0 to 4.52%
Sacrum	232	0.0376	0.0390	0.0067	0.0961	0.0185	0 to 7.6%
Os coxae	53	0.0193	0.0206	0.0066	0.0463	0.0089	0 to 3.84%
Femur	374	0.0171	0.0179	0.0000	0.0399	0.0059	0 to 2.97%
Tibia	192	0.0164	0.0181	0.0061	0.0496	0.0081	0 to 3.43%
Tarsals	417	0.0128	0.0136	0.0000	0.0451	0.0072	0 to 2.8%
Metatarsals	139	0.0102	0.0108	0.0026	0.0261	0.0046	0 to 2%

Table 5.31: Continued.

Measurement	N	Median	Mean	Minimum	Maximum	Std. Dev.	Confidence interval 95%
Upper Limb	64	0.0237	0.0237	0.0114	0.0398	0.0058	0 to 3.53%
Lower Limb	126	0.0174	0.0179	0.0084	0.0396	0.0055	0 to 2.89%
Upper long bone lengths	205	0.0101	0.0110	0.0000	0.0259	0.0058	0 to 2.26%
Lower long bone lengths	442	0.0062	0.0070	0.0000	0.0232	0.0043	0 to 1.56%
Midshafts	370	0.0350	0.0361	0.0136	0.0855	0.0107	0 to 5.75%
Upper limb midshafts	592	0.0414	0.0421	0.0074	0.1098	0.0148	0 to 7.17%
Lower limb midshafts	698	0.0261	0.0278	0.0045	0.0730	0.0118	0 to 5.14%
Shoulder	44	0.0264	0.0265	0.0110	0.0461	0.0090	0 to 4.45%
Elbow	176	0.0223	0.0235	0.0047	0.0551	0.0097	0 to 4.29%
Sacro-iliac joint	204	0.0361	0.0405	0.0041	0.1152	0.0220	0 to 8.45%
Hip	455	0.0123	0.0133	0.0028	0.0388	0.0059	0 to 2.51%
Knee	194	0.0128	0.0138	0.0019	0.0328	0.0062	0 to 2.62%

Similar to the adults, subadult average median FA was 2.04%, with a 95% confidence interval of between 0 to 6.33% ($\overline{x}$ =2.45% and σ=1.94%) (see Table 5.32). Measurements with the highest median FA include CVLC (9.51%), CDGL (6.41%), CVMC (5.27%), UIMS (4.73%), and CVWA (4.34%). There were no measurements with medians at zero. However, measurements with the lowest medians include FML (0.5%), TML (0.58%), MAL (0.66%), UML (0.73%), and UPL (0.74%). Subadults possessed less variability in FA than adults, with measurements with the greatest range, i.e. the highest standard deviation, including CVLC ($\overline{x}$ =10.67% and σ=7.54%), CDGL ($\overline{x}$ =7.42% and σ=5.74%), CVMC ($\overline{x}$ =6.19% and σ=4.89%), UIMS ($\overline{x}$ =5.55% and σ =4.21%), and OCASH ($\overline{x}$ =5% and σ=4.2%). The most stable measurements, those with the lowest standard deviation, included all of the long bone lengths: FML ($\overline{x}$ =0.62% and σ=0.55%), TML ($\overline{x}$ =0.68% and σ=0.59%), UML ($\overline{x}$ =0.88% and σ =0.72%), RML ($\overline{x}$ =0.87% and σ=0.72%), and HML ($\overline{x}$ =0.91% and σ=0.72%). Indices with the highest medians were the same as those for adults, including the clavicle (5.52%), temporal bone of the cranium (3.9%), and upper limb midshafts (3.85%). Those indices with the lowest medians include lower long bone lengths

(0.64%), upper long bone lengths (0.82%), and metatarsals (1.02%). Those indices with the highest ranges were also similar to those of the adults: the temporal bone of the cranium ($\overline{x}$ =4.63% and σ=2.39%), the clavicle ($\overline{x}$ =5.56% and σ=2.08%), and the sacrum ($\overline{x}$ =52.97% and σ=1.63%). The most stable indices include the lower limb ($\overline{x}$ =1.73% and σ=0.35%), long bone lengths ($\overline{x}$ =0.66% and σ=0.38%), and metatarsals ($\overline{x}$ =1.09% and σ=0.4%).

Table 5.32: Fluctuating asymmetry descriptive results for subadults.

Measurement	Valid N	Median	Mean	Minimum	Maximum	Std. Dev.	Confidence interval 95%
CFMTN	115	0.0098	0.0110	0.0000	0.0348	0.0084	0 to 2.78%
CMAH	141	0.0272	0.0302	0.0000	0.1089	0.0201	0 to 7.04%
CECMIS	120	0.0133	0.0155	0.0000	0.0461	0.0108	0 to 3.71%
CFMTB	45	0.0091	0.0146	0.0000	0.0529	0.0143	0 to 4.32%
CMPL	174	0.0250	0.0361	0.0000	0.1513	0.0348	0 to 10.57%
CMPB	174	0.0298	0.0410	0.0000	0.1764	0.0379	0 to 11.68%
CMSAST	132	0.0261	0.0327	0.0000	0.1227	0.0272	0 to 8.71%
CDGL	136	0.0641	0.0742	0.0000	0.2412	0.0574	0 to 18.9%
COCL	168	0.0239	0.0296	0.0000	0.1044	0.0253	0 to 8.02%
MAL	163	0.0066	0.0089	0.0000	0.0346	0.0079	0 to 2.47%
MRH	176	0.0117	0.0137	0.0000	0.0491	0.0105	0 to 3.47%
MXRB	144	0.0142	0.0213	0.0000	0.0781	0.0190	0 to 5.93%
MIRB	217	0.0209	0.0250	0.0000	0.1032	0.0188	0 to 6.26%
CVML	144	0.0126	0.0151	0.0000	0.0554	0.0120	0 to 3.91%
CVXMS	279	0.0421	0.0493	0.0000	0.1782	0.0358	0 to 12.09%
CVWA	159	0.0434	0.0517	0.0000	0.1917	0.0402	0 to 13.21%
CVWS	156	0.0359	0.0454	0.0000	0.1566	0.0379	0 to 12.12%
CVMC	70	0.0527	0.0619	0.0000	0.2085	0.0489	0 to 15.97%
CVLC	64	0.0951	0.1067	0.0000	0.3390	0.0754	0 to 25.75%
SGL	188	0.0213	0.0255	0.0000	0.0796	0.0179	0 to 6.13%
SGB	190	0.0260	0.0299	0.0000	0.1126	0.0233	0 to 7.65%
SAL	75	0.0349	0.0393	0.0000	0.1263	0.0280	0 to 9.53%
HML	195	0.0079	0.0091	0.0000	0.0279	0.0072	0 to 2.35%
HXMS	300	0.0274	0.0296	0.0000	0.1064	0.0215	0 to 7.26%
HIMS	299	0.0271	0.0324	0.0000	0.1178	0.0241	0 to 8.06%
HDT	250	0.0255	0.0309	0.0000	0.0994	0.0234	0 to 7.77%
HSIH	79	0.0167	0.0226	0.0000	0.0825	0.0181	0 to 5.88%
HAPH	72	0.0148	0.0206	0.0000	0.0690	0.0181	0 to 5.68%
HSMLD	157	0.0163	0.0189	0.0000	0.0658	0.0139	0 to 4.67%
HSMLP	156	0.0175	0.0221	0.0000	0.0761	0.0166	0 to 5.53%
HGT	42	0.0188	0.0314	0.0000	0.1625	0.0346	0 to 10.06%
RML	124	0.0075	0.0087	0.0000	0.0320	0.0072	0 to 2.31%
RXMS	273	0.0355	0.0405	0.0000	0.1364	0.0289	0 to 9.83%
RIMS	269	0.0364	0.0399	0.0000	0.1473	0.0290	0 to 9.79%
RGH	118	0.0253	0.0283	0.0000	0.0886	0.0225	0 to 7.33%
RSMLD	85	0.0221	0.0241	0.0000	0.0840	0.0190	0 to 6.21%

Table 5.32: Continued.

Measurement	Valid N	Median	Mean	Minimum	Maximum	Std. Dev.	Confidence interval 95%
RMLD	31	0.0153	0.0197	0.0034	0.0547	0.0139	0 to 4.75%
UML	110	0.0073	0.0088	0.0000	0.0319	0.0072	0 to 2.32%
UPL	105	0.0074	0.0097	0.0000	0.0353	0.0079	0 to 2.55%
UXMS	261	0.0314	0.0378	0.0000	0.1386	0.0281	0 to 9.4%
UIMS	267	0.0473	0.0555	0.0000	0.2007	0.0421	0 to 13.97%
URN	215	0.0229	0.0292	0.0000	0.1054	0.0236	0 to 7.64%
UOW	220	0.0313	0.0345	0.0000	0.1120	0.0259	0 to 8.63%
UCH	200	0.0175	0.0215	0.0000	0.0874	0.0183	0 to 5.81%
MC1L	60	0.0141	0.0167	0.0000	0.0484	0.0110	0 to 3.87%
MC2L	77	0.0111	0.0131	0.0000	0.0355	0.0091	0 to 3.13%
MC3L	74	0.0101	0.0126	0.0000	0.0390	0.0091	0 to 3.08%
MC4L	70	0.0125	0.0124	0.0000	0.0370	0.0092	0 to 3.08%
MC5L	48	0.0097	0.0114	0.0000	0.0339	0.0081	0 to 2.76%
SZAB	140	0.0272	0.0344	0.0000	0.0993	0.0246	0 to 8.36%
SZS1	157	0.0250	0.0272	0.0000	0.0948	0.0201	0 to 6.74%
OCH	158	0.0087	0.0091	0.0000	0.0327	0.0086	0 to 2.63%
OCIB	115	0.0075	0.0091	0.0000	0.0357	0.0082	0 to 2.55%
OCIS	180	0.0078	0.0100	0.0000	0.0400	0.0084	0 to 2.68%
OCASH	306	0.0389	0.0500	0.0000	0.1953	0.0420	0 to 13.4%
OCASB	211	0.0258	0.0287	0.0000	0.1012	0.0221	0 to 7.29%
FML	198	0.0050	0.0062	0.0000	0.0252	0.0055	0 to 1.72%
FXMS	295	0.0192	0.0237	0.0000	0.0937	0.0195	0 to 6.27%
FIMS	299	0.0194	0.0250	0.0000	0.1014	0.0213	0 to 6.76%
FXST	312	0.0235	0.0309	0.0000	0.1182	0.0252	0 to 8.13%
FIST	316	0.0300	0.0372	0.0000	0.1404	0.0298	0 to 9.68%
FSMLD	110	0.0141	0.0156	0.0000	0.0574	0.0129	0 to 4.14%
FEB	75	0.0095	0.0108	0.0000	0.0368	0.0087	0 to 2.82%
FLE	122	0.0141	0.0166	0.0000	0.0642	0.0146	0 to 4.58%
FAPH	162	0.0123	0.0153	0.0000	0.0575	0.0132	0 to 4.17%
FSIH	153	0.0111	0.0144	0.0000	0.0533	0.0117	0 to 3.78%
FMLP	255	0.0108	0.0133	0.0000	0.0524	0.0113	0 to 3.59%
TML	174	0.0058	0.0068	0.0000	0.0267	0.0059	0 to 1.86%
TXNF	276	0.0243	0.0287	0.0000	0.0946	0.0218	0 to 7.23%
TINF	275	0.0263	0.0323	0.0000	0.1313	0.0277	0 to 8.77%
TSMLP	87	0.0120	0.0160	0.0000	0.0605	0.0143	0 to 4.46%
TMLP	89	0.0112	0.0119	0.0000	0.0359	0.0084	0 to 2.87%
TMC	52	0.0150	0.0173	0.0000	0.0610	0.0143	0 to 4.59%
TLC	55	0.0141	0.0179	0.0030	0.0536	0.0138	0 to 4.55%
CZL	121	0.0083	0.0098	0.0000	0.0355	0.0085	0 to 2.68%
CZB	102	0.0181	0.0170	0.0000	0.0505	0.0129	0 to 4.28%
CZH	103	0.0153	0.0170	0.0000	0.0625	0.0144	0 to 4.58%
TZL	106	0.0088	0.0120	0.0000	0.0513	0.0121	0 to 3.62%
TZB	97	0.0172	0.0176	0.0000	0.0645	0.0149	0 to 4.74%
TZH	107	0.0151	0.0188	0.0000	0.0668	0.0171	0 to 5.3%
MT1L	111	0.0102	0.0117	0.0000	0.0415	0.0090	0 to 2.97%
MT2L	69	0.0107	0.0126	0.0000	0.0412	0.0102	0 to 3.3%
MT3L	62	0.0091	0.0107	0.0000	0.0372	0.0083	0 to 2.73%
MT4L	59	0.0084	0.0121	0.0000	0.0331	0.0090	0 to 3.01%
MT5L	56	0.0128	0.0149	0.0000	0.0455	0.0106	0 to 3.61%
Cranium	12	0.0282	0.0337	0.0205	0.0621	0.0141	0.55 to 6.19%
Cranium: Facial	19	0.0162	0.0159	0.0048	0.0258	0.0074	0.11 to 3.07%

Table 5.32: Continued.

Measurement	Valid N	Median	Mean	Minimum	Maximum	Std. Dev.	Confidence interval 95%
Cranium: Temporal	95	0.0390	0.0463	0.0110	0.1070	0.0239	0 to 9.41%
Mandible	119	0.0158	0.0177	0.0055	0.0437	0.0087	0.03 to 3.51%
Clavicle	44	0.0552	0.0556	0.0167	0.1101	0.0208	1.4 to 9.72%
Scapula	61	0.0291	0.0306	0.0030	0.0727	0.0133	0.4 to 5.72%
Humerus	21	0.0223	0.0225	0.0140	0.0321	0.0051	1.23 to 3.27%
Radius	2	0.0239	0.0239	0.0192	0.0287	0.0068	1.03 to 3.75%
Ulna	66	0.0254	0.0272	0.0089	0.0655	0.0119	0.34 to 5.1%
Metacarpals	16	0.0107	0.0123	0.0048	0.0228	0.0051	0.21 to 2.25%
Pelvic girdle	31	0.0211	0.0229	0.0078	0.0502	0.0101	0.27 to 4.31%
Sacrum	131	0.0270	0.0297	0.0000	0.0720	0.0163	0 to 6.23%
Os coxae	56	0.0195	0.0215	0.0055	0.0449	0.0098	0.19 to 4.11%
Femur	17	0.0163	0.0168	0.0094	0.0261	0.0050	0.68 to 2.68%
Tibia	16	0.0178	0.0182	0.0071	0.0330	0.0063	0.56 to 3.08%
Tarsals	50	0.0149	0.0142	0.0021	0.0282	0.0062	0.18 to 2.66%
Metatarsals	18	0.0102	0.0109	0.0027	0.0184	0.0040	0.29 to 1.89%
Upper Limb	1	0.0261	0.0261	0.0261	0.0261	x	x
Lower Limb	6	0.0172	0.0173	0.0125	0.0226	0.0035	1.03 to 2.43%
Upper long bone lengths	59	0.0082	0.0091	0.0011	0.0285	0.0058	0 to 2.07%
Lower long bone lengths	117	0.0064	0.0066	0.0000	0.0184	0.0038	0 to 1.42%
Midshafts	102	0.0346	0.0350	0.0167	0.0654	0.0090	1.7 to 5.3%
Upper limb midshafts	182	0.0385	0.0390	0.0115	0.0814	0.0125	1.4 to 6.4%
Lower limb midshafts	224	0.0252	0.0269	0.0029	0.0714	0.0125	0.19 to 5.19%
Shoulder	12	0.0305	0.0321	0.0159	0.0527	0.0125	0.71 to 5.71%
Elbow	54	0.0240	0.0261	0.0040	0.0634	0.0118	0.25 to 4.97%
Hip	116	0.0128	0.0140	0.0018	0.0442	0.0076	0 to 2.92%
Knee	11	0.0140	0.0123	0.0074	0.0221	0.0045	0.33 to 2.13%

5.6.2 Population Comparisons by Sex

Male and female mean median fluctuating asymmetry scores for all measurements were found to be almost equal, with females having an average median of 1.99% and a 95% confidence interval of between 0% and 6.53% ($\overline{x}$ =2.46% and σ=2.04%), and males at 2% with a 95% confidence interval of between 0% and 6.52% ($\overline{x}$ =2.46% and σ =2.03%) (see Table AP 8.1). Results from Mann-Whitney *U*-tests indicate that there were significant differences in fluctuating asymmetry between males and females in 19 measurements and six indices (see Tables 5.33 and AP 9.1). Of the measurements, nine significant differences were located in the upper limb (mainly in the humerus), one in the pelvic girdle, six in the lower limb and foot, and three in the cranium. No significant differences were found in the mandible, clavicle, hand, sacrum, or metatarsals. Although no single measurement for the scapula was found to be significant, males and females differed significantly in an overall scapular index.

Table 5.33: Significant results for fluctuating asymmetry from Mann Whitney-*U* tests comparing males with females. (*p significant after a Bonferroni adjustment).

Measurement	Female N	Male N	Z	p-Value
CMSAST	305	428	2.2032	0.0276
COCL	287	405	3.1883	0.0014
CNMS	134	208	0.1451	0.0362
HML	194	357	4.7300	<0.00001*
HXMS	363	529	-5.0397	<0.00001*
HIMS	363	524	-3.0438	0.0023
HDT	357	515	-3.2925	0.001
HAPH	199	325	-3.3307	0.0009
HGT	178	304	-3.0438	0.0023
RML	167	298	5.2065	<0.00001*
UML	113	250	5.0129	<0.00001*
UPL	167	302	4.4776	<0.00001*
OCAH	268	424	2.0013	0.0454
FIST	369	587	2.7989	0.0051
TMLP	168	316	3.4756	0.0005*
CZL	246	410	2.8947	0.0038
CZB	212	383	2.1614	0.0307
CZH	260	426	3.9141	0.0001*
TZH	234	421	2.4881	0.0128
Cranium: Temporal	218	325	2.8134	0.0049
Scapula	20	45	2.3452	0.019
Humerus	108	196	-4.1227	<0.00001*
Upper long bone lengths	54	150	4.7959	<0.00001*
Midshafts	122	191	-1.9965	0.0459
Upper limb midshafts	190	308	-2.6610	0.0078

5.6.3 Population Comparisons by Age-at-Death

Both adults and subadults had similar average median fluctuating asymmetry scores (see Table AP 8.2). The average median FA for subadults was 2.07% with a 95% confidence interval of 0 to 6.42% ($\bar{x}$ =2.48% and σ=2.07%), while adults had an average median of 2.04% and a range of 0 to 6.56% ($\bar{x}$ =2.48% and σ=2.04%). Mann

Whitney-*U* tests of fluctuating asymmetry scores found significant differences in 31 of the 83 measurements compared between the groupings of subadult and adult population (see Tables 5.34 and AP 9.2). The majority of the differences were in the upper limb, shoulder and hand, with 15 significant differences. There were five measurements with significant differences between the age groups in the skull, three in the pelvic girdle, with the remaining eight in the lower limbs and feet.

Table 5.34: Significant results for fluctuating asymmetry from Mann Whitney-*U* tests comparing adults with subadults. (*p significant after a Bonferroni adjustment).

Measurement	Adult N	Subadult N	Z	p-value
CFMTB	504	45	-3.7193	0.0002*
CMPB	806	174	-4.3198	<0.00001*
COCL	538	168	2.7077	0.0068
MXRB	389	144	3.1574	0.0016
MIRB	710	217	2.4835	0.013
CVML	484	144	3.1149	0.0018
SGL	505	188	-3.8187	0.0001*
SGB	511	190	-2.1236	0.0337
SAL	227	75	-3.0178	0.0025
HML	552	195	4.3124	<0.00001*
HXMS	895	300	2.5680	0.0102
HDT	875	250	1.9899	0.0466
RGH	356	118	-3.1662	0.0015
UML	364	110	1.9793	0.0478
UXMS	800	261	2.9538	0.0031
URN	749	215	-2.8428	0.0045
UOW	697	220	-2.4967	0.0125
UCH	540	200	2.4990	0.0125
MC1L	524	60	-2.4100	0.016
MC2L	541	77	-2.8749	0.004
SZAB	548	140	4.4691	<0.00001*
OCH	275	158	-3.5994	0.0003*
OCIS	421	180	-2.2475	0.0246
FML	695	198	2.2343	0.0255
FXMS	933	295	2.8908	0.0038
FIST	959	316	-3.2030	0.0014
FLE	622	122	-2.5357	0.0112
TMLP	488	89	-2.7013	0.0069
CZL	661	121	-2.8270	0.0047
CZB	599	102	-2.2748	0.0229
TZH	660	107	-3.3384	0.0008

The average median fluctuating asymmetry score for specific adult age groups were found to be similar, with slightly higher levels as age progressed (see Table AP 8.3). The average median FA for young adults was 1.92% with a range with a 95% confidence interval of 0 to 6.44% ($\bar{x}$ =2.41% and σ=2.02%), for middle adults the average median was 1.97% with a range of 0 to 6.42% ($\bar{x}$ =2.41% and σ=2%), and for mature adults the average median was 2.09% with a range of 0 to 6.75% ($\bar{x}$ =2.55% and σ=2.1%). Kruskal-Wallis ANOVA tests indicate that between specific adult age groups only four measurements and two indices significantly differed (see Table AP 9.3). Significant differences between adult age groups include CBPO (H=8.4762, p=0.0144), UXMS (H=10.4559, p=0.0054), MC4L (H=6.7252, p=0.0346), OCAH (H=6.7761, p=0.0338), the mandible (H=7.983, p=0.0185), and the tarsals (H=7.0536, p=0.0294). However, after a sequential Bonferroni adjustment none of the measurements remain significant. Post-hoc tests (see Tables 5.35, AP 9.5, and the electronic appendix) revealed these significant differences were between middle adults and mature adults in all but the tarsals, which had significant differences between all age groups, except between middle and mature adults.

Table 5.35: Significant differences in fluctuating asymmetry from post-hoc tests between adult age groups. (MA=Mature Adult, MDA=Middle Adult, and YA=Young Adult).

Measurement/Index	Differences are Between:	P
CBPO	MA and MDA	0.025
UXMS	MA and MDA	0.0088
MC4L	MA and MDA	0.0309
OCAH	MA and MDA	0.0336
Mandible	MA and MDA	0.0192
Tarsals	MA and YA	0.0351
	MDA and YA	0.0385

The average median fluctuating asymmetry score for specific subadult age groups decreased with age from foetal to infancy to late childhood, and then rose again in adolescent (see Table AP 8.4). Of all the age groups, foetal to infant had the highest mean median FA at 2.44% with a 95% confidence interval of between 0 and 6.98% ($\bar{x}$ =2.81% and σ=2.08%). The mean median FA for early childhood was 2.04% with a range of 0 to 6.35% ($\bar{x}$ =2.45% and σ=1.95%), a median for late childhood of 2% with a range of 0 to 6.32% ($\bar{x}$ =2.45% and σ=1.93%), and a median for adolescent of 2.13% with a range of 0 to 6.24% ($\bar{x}$ =2.45% and σ=1.89%). Significant differences from Kruskal-Wallis ANOVA tests were found between subadult age groupings in 10 measurements and two indices (see Tables 5.36 and AP 9.4). Post-hoc tests suggest significant differences exist between subadult age groups in nine measurements and both indices (see Tables 5.37, AP 9.6, and the electronic appendix), which is unlike the adults, where there were two specific age groups, middle and mature adults, that frequently differed. Although the lower limb midshafts did not differ from ANOVA tests, this index differed significantly between the groupings foetal to infant to late childhood during post-hoc testing.

Table 5.36: Significant results for fluctuating asymmetry from Kruskal-Wallis ANOVA tests for between subadult age groups. (*p significant after a Bonferroni adjustment).

Measurement	D	N	H	p-Value
CMPB	2	174	6.1512	0.0462
HML	3	195	21.3491	0.0001*
HSMLP	3	156	14.8224	0.002
RMLD	2	31	4.9705	0.0258
OCH	3	158	11.7123	0.0084
OCIS	3	180	8.8514	0.0313
FIMS	3	299	8.9471	0.03
FSMLD	3	110	9.0896	0.0281
TMLP	2	89	11.9491	0.0025
TZB	2	97	7.3875	0.0249
Tarsals	2	50	12.0073	0.0025*
Upper limb midshafts	3	182	10.0362	0.0183*
Lower limb midshafts	3	224	7.6266	0.0544

Table 5.37: Significant differences for fluctuating asymmetry from post-hoc tests between subadult age groups. (*AD=Adolescent, LC=Late Childhood, EC=Early Childhood, and FI=Foetal to Infant).

Measurement/Index	Differences are Between:	P
HML	EC and AD	0.0009
	EC and LC	0.0017
HSMP	EC and LC	0.018
	FI and EC	0.0097
RMLD	LC and AD	0.0258
OCH	FI and LC	0.008
	FI and EC	0.0117
OCIS	EC and LC	0.0347
FIMS	FI and AD	0.0487
	FI and AD	0.0223
FSMLD	FI and AD	0.0429
TMLP	EC and AD	0.0017
TZB	LC and AD	0.0367
Tarsals	LC and AD	0.0396
	EC and AD	0.0042
Upper limb midshafts	FI and EC	0.0122
Lower limb midshafts	FI and LC	0.0404

5.6.4 Population Comparisons by Site

The highest average median fluctuating asymmetry score for adults from specific archaeological sites was from Hickleton at 2.53% with a 95% confidence interval of 0 to 7.02% ($\bar{x}$ =2.87% and σ=2.07%), followed by Wolverhampton at 2.39% with a range of 0 to 7.47% ($\bar{x}$ =2.39% and σ=2.29%) (see Table AP 8.5). The lowest average median FA score was Hereford at 1.89% with a range of 0-6.14% ($\bar{x}$ =2.31% and σ=1.92%), followed by Fishergate at 1.91% with a range of 0-6.41 ($\bar{x}$ =2.39% and σ=2.01%) and by York Minster at 1.94% with a range of 0-6.08% ($\bar{x}$ =2.33% and σ=1.88%). York Minster had the least variation in population FA scores, while Wolverhampton had the highest.

Population comparisons between adults from the 11 studied archaeological sites found significant differences from Kruskal-Wallis ANOVA tests for 33 measurements and nine indices (see Tables 5.38 and AP 9.3). From the cranium, 13 measurements—more than one half of the observed cranial traits—differed significantly between sites. The remaining significant differences were found throughout the post-cranial skeleton, with 11 in the upper limb, shoulder and hand and nine in the lower limb and ankle. There were no significant differences in measurements for the mandible, pelvic girdle, or metatarsals. Post-hoc analysis indicates that of these measurements and indices, significant differences were found between specific sites for 17 measurements and six indices (see Tables 5.39, AP 9.7, and the electronic appendix). Although not significant during ANOVA tests, measurements CMPH, CVLC, and FISH differed significantly between specific sites during post-hoc testing. The sites with the most significant differences between it and another site were York Minster with 16 and Wharram Percy with 14 significant differences in FA. These were followed by Chichester with 14 and Fishergate with 10 significant differences. Wolverhampton and Towton had the least number of significant differences between sites. The two sites with the most significant differences between them were Chichester and York Minster, with six measurements differing in FA.

Table 5.38: Significant results for fluctuating asymmetry from Kruskal-Wallis ANOVA tests for between site comparisons for adults. (*p significant after a Bonferroni adjustment).

Measurement	D	N	H	p-Value
COBH	7	226	15.9867	0.0252
CNOR	7	219	14.6038	0.0414
CMPL	10	736	34.5014	0.0002*
CMPB	10	806	23.1614	0.0102
CMPH	10	695	18.0027	0.0549
CMSAST	10	691	19.6085	0.0332
COCL	10	538	22.0498	0.0149
CECMIS	10	363	21.9025	0.0156
COPO	8	360	20.8187	0.0076
CBPO	9	384	32.24	0.0002*
CBZO	7	210	15.4798	0.0303
CNMS	8	319	17.4473	0.0258
CBAST	9	472	20.6215	0.0144
CLFMT	9	416	23.6764	0.0048
CVWA	10	550	23.0969	0.0104
CVMC	10	465	26.3407	0.0033

Table 5.38: Continued.

Measurement	D	N	H	p-Value
CVLC	10	452	14.0097	0.1726
SGL	10	505	18.7829	0.0431
HML	10	552	21.9308	0.0155
HXMS	10	895	26.2287	0.0034
HDT	10	875	25.1582	0.0051
HGT	10	484	33.9099	0.002
RML	10	466	23.6056	0.0087
UOW	10	697	18.6311	0.0452
MC2L	9	537	20.6587	0.0143
MC5L	10	445	24.0037	0.0076
FXST	10	948	22.3956	0.0132
FIST	10	959	31.0126	0.0006
FEB	10	624	19.8244	0.031
FSIH	10	894	17.4968	0.0641
FMLP	10	747	32.2133	0.0004*
TXNF	10	814	20.4	0.0257
TMC	10	318	26.8392	0.0028
CZL	10	661	21.1191	0.0203
CZB	10	599	22.7152	0.0119
TZL	10	630	21.2893	0.0192
Cranium: Orbit	7	199	20.6899	0.0043
Cranium: Facial	6	119	13.359	0.0377
Cranium: Temporal	10	546	37.2663	0.0001*
Cranium: Base	7	209	26.3958	0.0004*
Cranium: Vault	8	322	23.618	0.0027
Humerus	10	305	20.2316	0.0271
Lower limb	6	113	13.1796	0.0403
Lower limb midshafts	10	698	36.5499	0.0001*
Hip	10	455	30.3883	0.0007*

Table 5.39: Significant differences in fluctuating asymmetry in adults from post-hoc tests between sites. (BF= Blackfriars, OCH=Chelsea, CH=Chichester, FG=Fishergate, HE=Hereford, HK=Hickleton, SH=St. Helen's, TO=Towton, WP=Wharram Percy, HCW=Wolverhampton, and YM=York Minster).

Measurement/Index	Differences are Between:	P
CMPL	BF and FG	0.0254
	BF and YM	0.0339
	FG and WP	0.0054
	WP and YM	0.0135
CMPB	CH and YM	0.018
CMPH	HK and TO	0.0141
CMSAST	CH and SH	0.0438
COCL	OCU and YM	0.016
CECMIS	HK and YM	0.016
CBPO	CH and YM	0.0153
	HK and YM	0.0077
	WP and YM	0.0422
CBZO	WP and YM	0.0126
CLFMT	CH and YM	0.007
CVMC	HK and SH	0.0234
	SH and HCW	0.0462

Table 5.39: Continued.

Measurement/Index	Differences are Between:	P
CVLC	BF and HK	0.0351
HXMS	BF and WP	0.0166
	HK and WP	0.0055
HDT	CH and WP	0.0271
	HE and WP	0.0139
	SH and WP	0.0426
HGT	OCH and FG	0.0317
	FG and SH	0.0012
	FG and WP	0.0183
MC5L	OCU and SH	0.0425
	OCU and WP	0.0272
FIST	CH and HE	0.0014
	CH and WP	0.0209
	FG and HE	0.0013
	HE and SH	0.0237
FSIH	FG and TO	0.0347
TXNF	OCU and FG	0.037
TMC	WP and HCW	0.0244
TZL	BF and CH	0.0443
Cranium: Orbit	FG and YM	0.0241
Cranium: Temporal	CH and TO	0.0211
	HK and TO	0.0012
	HK and YM	0.0218
	TO and HCW	0.0405
Cranium: Base	CH and YM	0.0004
Cranium: Vault	CH and YM	0.0063
	WP and YM	0.0476
Lower limb midshafts	CH and FG	0.0348
	CH and HE	0.015
	CH and YM	0.0334
Hip	FG and SH	0.043

Subadults from specific sites consistently had higher FA scores than their adult counterparts, except at Wolverhampton where adults had higher levels of FA than subadults (see Table AP 8.6). Wolverhampton, however, did have the highest average median fluctuating asymmetry score for subadults from specific archaeological sites at 2.93% with a 95% confidence interval of 0 to 7.46% ($\bar{x}$ =3.1% and σ=2.18%), followed by Hickleton at 2.87% with a range of 0 to 6.72% ($\bar{x}$ =3.02% and σ=1.85%). The lowest average median FA score was from Wharram Percy at 1.89% with a range of 0-5.33% ($\bar{x}$ =2.2% and σ=1.57%), followed by Hereford at 1.89% with a range of 0-5.33% ($\bar{x}$ =2.2% and σ=1.57%). Hereford and Wharram Percy had the least range in population FA scores, while Wolverhampton and Chichester (range of 0-6.41%, $\overline{x}$ =2.65% and σ=1.88%) had the highest.

Subadults had fewer measurements with significant differences between the sites than did the adult populations. Between site comparisons for subadults found 14 measurements and five indices with significant differences (see Tables 5.40 and AP 9.4). Of these measurements, two were in the cranium, four in the upper limb, three in the pelvic girdle, and five in the lower limb and foot. Post-hoc tests indicate that of those measurements and indices which had overall significant differences (see Tables 5.41, AP 9.8, and the electronic appendix), only two did not involve Wharram Percy. The majority of significant differences were between populations from Fishergate and Wharram Percy. It was also found that after post-hoc testing, FA levels in RGH differed between Wharram Percy and Wolverhampton, although this was not reflected in overall ANOVA between site comparisons.

Table 5.40: Significant results for fluctuating asymmetry from Kruskal-Wallis ANOVA tests for between site comparisons for subadults. (*p significant after a Bonferroni adjustment).

Measurement	D	N	H	p-Value
CMAH	6	133	16.372	0.0119
CMPL	7	170	25.8334	0.0005*
SGL	8	186	19.2997	0.0133
HXMS	8	297	16.6672	0.0338
RGH	7	114	11.84426	0.1058
URN	7	211	16.4174	0.0216
UOW	8	218	15.8434	0.0447
SZS1	5	146	13.1479	0.022
OCIS	8	178	20.5407	0.0085
OCASH	8	305	18.4046	0.0184
FXST	8	311	34.8937	<0.00001*
FIST	8	315	33.2988	0.0001*
TINF	8	272	22.6358	0.0039
CZL	4	107	9.6385	0.047
MT1L	4	101	11.874	0.0183
Cranium: Temporal	5	87	14.0244	0.0155
Ulna	3	57	11.8584	0.0079
Midshafts	7	100	18.9031	0.0085
Lower limb midshafts	8	223	17.9874	0.0213
Elbow	2	44	12.4965	0.0019*

Table 5.41: Significant differences in fluctuating asymmetry in subadults from post-hoc tests between sites. (CH=Chichester, FG=Fishergate, HE=Hereford, HK=Hickleton, SH=St. Helen's, WP=Wharram Percy, HCW=Wolverhampton, and YM=York Minster).

Measurement/Index	Differences are Between:	P
CMAH	SH and WP	0.0282
CMPL	FG and WP	0.0149
SGL	WP and HCW	0.0133
RGH	WP and FG	0.0458
OCIS	FG and HE	0.0317
FXST	CH and WP	0.0013
	FG and WP	0.0313
	WP and HCW	0.0005
FIST	CH and WP	0.0095
	FG and WP	0.0233
	SH and WP	0.0356
	WP and HCW	0.0042
TINF	CH and WP	0.018
	FG and WP	0.0207
CZL	FG and HE	0.0419
Cranium: Temporal	HE and WP	0.0089
Ulna	SH and WP	0.0212
Elbow	FG and WP	0.005
	SH and WP	0.0232

5.6.5 Population Comparisons by Settlement Type

Average median fluctuating asymmetry scores for adults divided into settlement type were similar for all environments (see Table AP 8.7). Adults from urban environments had the lowest median FA scores and the least range, at 1.91% with a 95% confidence interval of 0 to 6.38% ($\overline{x}$ =2% and σ=2.39%), followed by rural environments at 2.12% with a range of 0 to 6.67% ($\overline{x}$ =2.55% and σ=2.06%). The *leprosarium*/almshouse environment at Chichester had an average median of 2.12% with a slightly higher range of 0 to 6.83% ($\overline{x}$ =2.59% and σ=2.12%).

Kruskal-Wallis ANOVA tests for comparisons of the adult population based on settlement type found 25 measurements with significant differences and seven indices (see Tables 5.42 and AP 9.3). Eleven of the measurements with significant differences were from the cranium, one from the mandible, one from the clavicle, four from the upper limb and hand, one from the sacrum, and seven from the lower limb and foot. No significant differences in measurements were found in the scapula, radius, ulna, *os coxae*, and metatarsals. Post-hoc analysis indicates that of these measurements and indices, significant differences occurred between specific settlement type for 21 measurements and six indices (see Tables 5.43, AP 9.9, and the electronic appendix). Urban environments had the most significant differences of the settlement types, *leprosarium*/almshouses the least. Most of the significant differences occurred between urban and rural settlements.

Table 5.42: Significant results for fluctuating asymmetry from Kruskal-Wallis ANOVA tests for between settlement type comparisons for adults. (*p significant after a Bonferroni adjustment).

Measurement	d	N	H	p-Value
COBB	2	233	7.1002	0.0287
CMPL	2	720	15.4215	0.0004*
CMPB	2	790	7.0835	0.029
CMSAST	2	677	8.4621	0.0145
COCL	2	533	12.5352	0.0019
COPO	2	364	8.8072	0.0122
CBAPO	2	341	7.136	0.0282
CBPO	2	384	17.7946	0.0001*
CBZO	2	213	6.6436	0.0361
CNMS	2	323	6.176	0.0456
CLFMT	2	416	7.6745	0.0216
MAL	2	520	9.1643	0.0102
CVWA	2	535	10.7931	0.0045
HSIH	2	617	10.961	0.0042
HGT	2	468	7.9909	0.0184
MC2L	2	537	6.7089	0.0349
MC3L	2	517	6.6686	0.0356
SZAB	2	538	9.0016	0.0111
FXST	2	920	6.381	0.0412
FIST	2	932	10.1279	0.0063
FEB	2	603	6.1062	0.0472
TMLP	2	471	8.6281	0.0134
CZL	2	643	8.2144	0.0165
CZB	2	580	7.079	0.029
TZL	2	609	8.0651	0.0177
Cranium	1	55	3.8585	0.0495
Cranium: Orbit	2	202	6.8423	0.0327
Cranium: Temporal	2	538	10.2414	0.006
Cranium: Base	2	214	15.1883	0.0005*
Cranium: Vault	2	326	10.8952	0.0043
Tarsals	2	401	6.5959	0.037
Lower limb midshafts	2	675	13.2688	0.0013*

Table 5.43: Significant differences in fluctuating asymmetry in adults from post-hoc tests between settlement types. (L/A=*leprosarium*/almshouse, R=rural, and U=urban).

Measurement/Index	Differences are Between:	P
COBB	L/A and R	0.0443
CMPL	L/A and U	0.0337
	U and R	0.0015
CMPB	L/A and U	0.0439
CMSAST	L/A and U	0.0189
COCL	U and R	0.0026
COPO	L/A and U	0.0346
CBAPO	L/A and U	0.0293
CBPO	L/A and U	0.0213
	U and R	0.0006
CBZO	U and R	0.0454
MAL	U and R	0.0136
CVWA	U and R	0.0031
HISH	U and R	0.0043
HGT	U and R	0.0306
MC2L	U and R	0.0365
MC3L	U and R	0.0299
SZAB	L/A and R	0.0196
FIST	L/A and R	0.0047
TMLP	L/A and U	0.0261
CZL	U and R	0.0239
CZB	L/A and R	0.0366
TZL	L/A and U	0.0236
Cranium	U and R	0.0495
Cranium: Temporal	L/A and U	0.0153
Cranium: Base	L/A and U	0.0008
	L/A and R	0.0307
Cranium: Vault	L/A and U	0.0293
	U and R	0.0264
Tarsals	L/A and R	0.0413
Lower limb midshafts	L/A and U	0.0008

Average median fluctuating asymmetry scores for subadults divided by settlement type were higher than those for corresponding adults groups, except for the rural environment where subadults had lower levels of FA than did adults (see Table AP 8.8). Unlike the adults, subadults from rural environments had the lowest FA scores and possessed the smallest range, at 1.88% with a 95% confidence interval of 0 to 5.94% ($\overline{x}$ =2.27% and σ=1.83%). Urban settlements had a average median of 2.1% with a range of 0 to 6.38% ($\overline{x}$ =2.5% and σ=1.94%), while those individuals from the *leprosarium*/almshouse at Chichester had the highest FA levels, and the greatest range, at 2.37% with a range of 0 to 6.86% ($\overline{x}$ =2.71% and σ=2.07%).

Kruskal-Wallis ANOVA comparisons for subadults from differing settlement types found significant differences in 18 measurements and six indices (see Tables 5.44 and AP 9.4). Of the measurements, three were in the cranium, six in the upper limb and shoulder, three in the pelvic girdle, and six in the lower limb and foot. Post-hoc tests indicate that fifteen measurements and five indices had significant differences between specific settlement types. There were no differences found between *leprosarium*/almshouse and urban environments (see Tables 5.45, AP 9.10, and the electronic appendix). All significant differences involved the rural environment, with a slight majority between rural and urban settlements.

Table 5.44: Significant results for fluctuating asymmetry from Kruskal-Wallis ANOVA tests for between settlement type comparisons for subadults. (*p significant after a Bonferroni adjustment).

Measurement	d	N	H	p-Value
CMAH	2	141	11.3344	0.0035
CMPL	2	174	14.1121	0.0009
MAL	2	163	5.9897	0.05
SGL	2	188	10.7749	0.0046
SGB	2	190	7.9481	0.0188
HSMLP	2	156	6.0061	0.0496
URN	2	215	10.4942	0.0053
UOW	2	220	10.6877	0.0048
UCH	2	200	7.6827	0.0215
SZS1	2	157	7.5435	0.023
OCIS	2	180	7.1347	0.0282
OCASH	2	306	6.0865	0.0477
FXST	2	312	21.2983	<0.00001*
FIST	2	316	20.5786	<0.00001*
FEB	2	75	6.4526	0.0397
TINF	2	275	14.2263	0.0008
TZH	2	107	8.9453	0.0114
MT1L	2	111	7.7668	0.0206
Scapula	1	59	3.8792	0.0489
Ulna	2	66	10.9473	0.0042
Sacrum	2	131	6.5834	0.0372
Midshafts	2	102	13.4399	0.0012*
Lower limb midshafts	2	224	8.6055	0.0135
Elbow	1	53	101.2434	0.0014*

Table 5.45: Significant differences in fluctuating asymmetry in subadults from post-hoc tests between settlement types. (L/A=*leprosarium*/almshouse, R=rural, and U=urban).

Measurement/Index	Differences are Between:	P
CMAH	U and R	0.0039
CMPL	L/A and R	0.0269
	U and R	0.0013
SGL	L/A and R	0.0158
	U and R	0.0303
SGB	L/A and R	0.0209
URN	L/A and R	0.0416
	U and R	0.0149
UOW	U and R	0.0043
UCH	U and R	0.0184
SZS1	L/A and R	0.0183
OCASH	L/A and R	0.0412
FXST	L/A and R	0.0007
	U and R	<0.00001
FIST	L/A and R	0.0024
	U and R	<0.00001
FEB	L/A and R	0.034
TINF	L/A and R	0.0041
	U and R	0.0037
TZH	L/A and R	0.0355
	U and R	0.0392
MT1L	L/A and R	0.0202
Scapula	U and R	0.0489
Ulna	U and R	0.0052
Midshafts	U and R	0.0016
Lower limb midshafts	U and R	0.0215
Elbow	U and R	0.0014

5.6.6 Population Comparisons by Period

Similar to directional asymmetry, the average median fluctuating asymmetry increased with time (see Table AP 8.9). Average median adult fluctuating asymmetry levels were slightly higher in the post-Medieval period at 2.29% with a 95% confidence interval of 0 to 7.17% ($\overline{x}$ =2.76% and σ=2.2%), followed by the Medieval period at 1.98% with a range of 0 to 6.48% ($\overline{x}$ =2.44% and σ=2.02%), and then the Anglo-Saxon period, with the lowest levels at 1.91% and a range of 0 to 6.15% ($\overline{x}$ =2.23% and σ=1.92%).

Kruskal-Wallis ANOVA tests for comparisons of adult populations based on period found 27 measurements and 16 indices with significant differences and an additional measurement with borderline significance (see Tables 5.46 and AP 9.3). Ten of the measurements with significant differences were from the cranium, one from the mandible, two from the shoulder, six from the upper limb and hand, one from the sacrum, and six from the lower limb and foot. There were no significant differences in measurements of the ulna, *os coxae*, and talus. Of all the population comparisons in this study, comparisons by period had the most overall indices with significant differences. Post-hoc analysis indicates that of these measurements and indices, significant differences occurred between specific period for 25 measurements and 14 indices (see Tables 5.47, AP 9.11, and the electronic appendix). The majority of these significant differences were between the post-medieval population and the other two periods, with the most common differences between Anglo-Saxon and post-medieval sites. The lowest number of differences occurred between the Anglo-Saxon and the Medieval periods. The Anglo-Saxon populations had the most differences with the other periods in cranial measurements. In addition, differences in the post-cranial skeleton between periods occurred most often between the Medieval and post-Medieval period.

Table 5.46: Significant results for fluctuating asymmetry from Kruskal-Wallis ANOVA tests for between period comparisons for adults. (*p significant after a Bonferroni adjustment).

Measurement	D	N	H	p-Value
CFMTN	2	531	6.2462	0.044
CMPL	2	671	6.4903	0.0402
CMPB	2	731	6.4956	0.0389
CMSAST	2	626	6.7329	0.0345
COCL	2	470	11.7356	0.0028
CECMIS	2	331	11.2679	0.0036
COPO	2	332	5.9782	0.0503
CBAPO	2	309	7.6682	0.0216
CBPO	2	347	14.5719	0.0007
CNMS	2	291	7.3492	0.0254
CLFMT	2	375	16.1049	0.0003*
MRH	2	474	7.3126	0.0258
CVMC	2	407	8.9847	0.0112
SGL	2	466	8.931	0.0115
HML	2	497	13.9633	0.0009
HDT	2	794	7.6657	0.0216

Table 5.46: Continued.

Measurement	D	N	H	p-Value
HAPH	2	469	6.8897	0.0319
RML	2	418	10.2887	0.0058
MC1L	2	465	8.4352	0.0147
MC2L	2	489	8.6492	0.0132
SZAPA	2	398	14.3858	0.0008
FEB	2	564	6.5003	0.0388
FMPL	2	674	7.9176	0.0191
TMC	2	291	6.1212	0.0469
TLC	2	297	10.8628	0.0044
CZL	2	607	13.8869	0.001
MT3L	2	334	12.634	0.0018
MT4L	2	318	8.8443	0.012
Cranium	2	52	8.9407	0.0114
Cranium: Orbit	2	186	6.2354	0.0443
Cranium: Facial	2	118	11.5012	0.0032
Cranium: Temporal	2	489	7.4085	0.0246
Cranium: Base	2	192	9.915	0.007
Cranium: Vault	2	291	20.1787	<0.00001*
Clavicle	2	236	12.1336	0.0023
Ulna	2	192	6.1471	0.0463
Metacarpals	2	141	6.0736	0.048
Sacrum	2	200	6.7837	0.0336
Upper long bone lengths	2	188	6.1111	0.0471
Midshafts	2	336	10.0632	0.0065
Upper limb midshafts	2	533	7.3671	0.0251
Lower limb midshafts	2	643	6.6723	0.0356
Hip	2	408	10.6393	0.0049
Knee	2	177	7.6478	0.0218

Table 5.47: Significant differences in fluctuating asymmetry in adults from post-hoc tests between periods. (AS=Anglo-Saxon, M=Medieval, PM=post-Medieval).

Measurement/Index	Differences are Between:	P
CFMTN	AS and PM	0.0376
CMSAST	AS and PM	0.0292
COCL	M and PM	0.0063
	AS and PM	0.0066
CECMIS	AS and M	0.0225
	AS and PM	0.0038
COPO	AS and PM	0.0441
CBAPO	AS and M	0.037
	AS and PM	0.0367
CBPO	AS and PM	0.0005
CNMS	AS and M	0.0347
CLFMT	AS and M	0.0011
	AS and PM	0.0023
MRH	AS and PM	0.0268
CVMC	M and PM	0.049
	AS and PM	0.0152
SGL	M and PM	0.0086
HML	M and PM	0.0025
HDT	M and PM	0.0187

Table 5.47: Continued.

Measurement/Index	Differences are Between:	P
HAPH	AS and M	0.026
RML	M and PM	0.0044
MC1L	M and PM	0.036
	AS and PM	0.031
MC2L	M and PM	0.0159
SZAPA	M and PM	0.0004
FEB	AS and PM	0.0412
FMLP	M and PM	0.0324
	AS and PM	0.0485
TCL	M and PM	0.0109
CZL	M and PM	0.0239
	AS and PM	0.0023
MT3L	M and PM	0.0014
MT4L	M and PM	0.0102
Cranium	AS and PM	0.0198
Cranium: Facial	AS and M	0.0225
	AS and PM	0.0039
Cranium: Temporal	AS and PM	0.0199
Cranium: Base	AS and PM	0.0062
Cranium: Vault	AS and M	0.0008
	AS and PM	<0.0001
Clavicle	M and PM	0.0097
	AS and PM	0.0036
Ulna	M and PM	0.0413
Sacrum	M and PM	0.0298
Upper long bone lengths	M and PM	0.0406
Midshafts	AS and PM	0.0061
Upper limb midshafts	AS and PM	0.0199
Lower limb midshafts	AS and PM	0.0314
Hip	M and PM	0.0047
Knee	M and PM	0.0422

Average median fluctuating asymmetry scores for subadults compared by period were higher than those of all corresponding adult groups (see Table AP 8.10). Similar to the situation found in the adult population, subadults from the post-Medieval period had the highest median FA scores at 2.37% and a 95% confidence interval of 0 to 6.88% ($\overline{x}$ =2.74% and σ=2.07%). Unlike the adult population, subadults from the Anglo-Saxon period were second highest at 2.21% with a range of 0 to 6.16% ($\overline{x}$ =2.47% and σ =1.85%), and individuals from the Medieval period had the lowest FA levels at 2.1% with a range of 0 to 6.39% ($\overline{x}$ =2.5% and σ=1.95%).

Unlike the large number of differences found between adults from specific periods, Kruskal-Wallis ANOVA comparisons for the subadult populations found significant differences in only five measurements and one index (see Tables 5.48 and AP 9.4). Of the measurements, three were in the cranium and one in the upper limb and one in the hand. Similarly, the only index to demonstrate significant differences between periods was the temporal bone of the cranium. Post-hoc tests demonstrate that the most differences occurred between the Anglo-Saxon and post-Medieval periods (see Tables 5.49, AP 9.12, and the electronic appendix).

Table 5.48: Significant results for fluctuating asymmetry from Kruskal-Wallis ANOVA tests for between period comparisons for subadults. (*p significant after a Bonferroni adjustment).

Measurement	d	N	H	p-Value
CECMIS	2	82	60613	0.0366
CMPL	2	122	9.1369	0.0104
CMPB	2	125	8.3299	0.0155
UML	2	67	7.8237	0.02
MC3L	1	47	4.005	0.0454
Cranium: Temporal	2	66	6.1931	0.0452

Table 5.49: Significant differences in fluctuating asymmetry in subadults from post-hoc tests between periods. (AS=Anglo-Saxon, M=Medieval, PM=post-Medieval).

Measurement/Index	Differences are Between:	P
CECMIS	M and PM	0.0326
CMPL	AS and M	0.0176
	AS and PM	0.0096
CMPB	AS and PM	0.0174
UML	AS and M	0.0451
	AS and PM	0.0164
MC3L	M and PM	0.0454
Cranium: Temporal	AS and PM	0.0428

5.7 Population Outliers

5.7.1 General Findings

Although normally studies of asymmetry would disregard population outliers, they are not ignored here because of their potential to provide important information about the health status of individuals and populations under study. This study hypothesises that through the examination of asymmetry population outliers, it is possible to determine the presence and extent of developmental instability, demographic differences, and important palaeopathological information about populations by the extreme nature of their individual asymmetries. As stated in Section 5.1, Grubb's Outlier tests found 830 measurements—1.16% of the total measurements taken—to be true population outliers, consisting of 600 adult measurements and 230 subadult measurements (see Appendix 4). After a conservative Bonferroni adjustment was applied, the number of outliers decreased to 130 for adults and 43 for subadults. However, as many of the measurements disregarded as outliers through the application of a Bonferroni adjustment were upon a second examination true population outliers (see Chapter 6.1.1), the following tests include all individuals found to be outliers at an alpha of $p<0.05$. The percentage of population outliers were then compared though chi-square tests for differences in sex, age-at-death, archaeological site, settlement type, and period.

5.7.2 Population Comparison by Sex

Although there are slight differences in the percentage of outlying measurements between males and females, a chi-square test indicates that there was no significant differences between the two sexes (χ^2 =0.13, p=0.7211) (see Figure 5.2 and Table AP 10.1). Of the 34,660 measurements taken from the male population 372, or 1.07%, were found to be significant outliers. Females had 226 outliers, or 1.04%, of their 21,704 measurements. Males were found to have a greater percentage of outlying measurements in every element and they had more than half as many outlying measurements for the femur and humerus and sacrum as females.

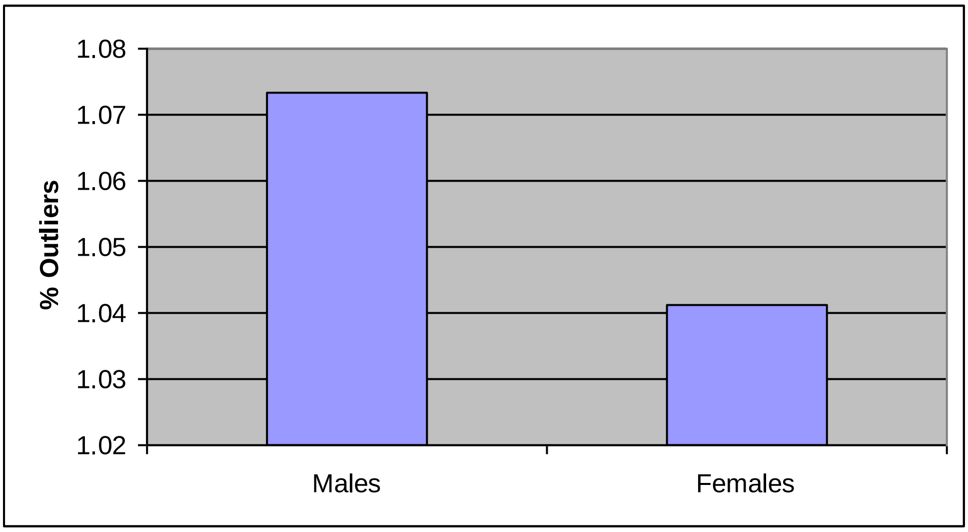

Figure 5.2: Percentage of measurements found to be significant population outliers for males and females.

5.7.3 Population Comparisons by Age-at-Death

Subadults had a significantly higher percentage of outliers than the adult population (χ^2 =44.69, p<0.0001) (see Tables 5.50 and AP 10.2). The age group foetal to infant was found to have the highest percentage of outlying measurements followed by late childhood and adolescent groups (see Table 5.50). Middle adults possessed the least percentage of outliers, followed by mature adults and then early childhood. Unlike those for sex differences, chi-square tests indicate that there were several significant differences in outliers between age groups (see Tables 5.51 and AP 10.2). The percentage of outliers from those individuals in the foetal to infant, late childhood, and adolescent groups differed significantly from individuals in early childhood and all adult age groups. Individuals in early childhood significantly differed from the other subadult age groups, but they were found to be similar to all adult groupings. Middle adults were found to differ from all groups, but the early childhood group. Lastly, young adults differed from all but the mature adults and early childhood groups, while mature adults differed from all but the young adults and early childhood groups.

Table 5.50: The number of outlying measurements for specific age groups.

Age	Outliers	Of	%
Subadults	230	12952	1.78
Adults	599	56569	1.06
Foetal to Infant	28	952	2.94
Early Childhood	53	4290	1.24
Late Childhood	90	4500	2.0
Adolescent	61	3210	1.9
Young Adult	81	6354	1.27
Middle Adult	293	30961	0.95
Mature Adult	212	17473	1.21

Table 5.51: Chi-square tests comparing specific age groups. (*P<0.05, FI=Foetal to Infant, EC=Early Childhood, LC=Late Childhood, AD=Adolescent, YA=Young Adults, MDA=Middle Adults, and MA=Mature Adults).

Age Group		Chi-Square	P-Value	Age Group		Chi-Square	P-Value
FI	EC	14.29	0.0002*	EC	FI	14.29	0.0002*
	LC	3.13	0.0769		LC	7.77	0.0053*
	AD	3.62	0.057		AD	5.25	0.0219*
	YA	15	0.0001*		YA	0.03	0.86
	MDA	32.52	<0.00001*		MDA	3.17	0.075
	MA	20.12	<0.00001*		MA	0.01	0.9069
LC	FI	3.13	0.0769	AD	FI	3.62	0.057
	EC	7.77	0.0053*		EC	5.25	0.0219*
	AD	0.09	0.7601		LC	0.09	0.7601
	YA	8.65	0.0033*		YA	5.53	0.0187*
	MDA	39.65	<0.00001*		MDA	25.09	<0.00001*
	MA	15.82	0.0001*		MA	9.53	0.002*
YA	MDA	5.61	0.0179*	MDA	YA	5.61	0.0179*
	MA	0.14	0.7068		MA	7.55	0.006*
	FI	15	0.0001*		FI	32.52	<0.00001*
	EC	0.03	0.86		EC	3.17	0.075
	LC	8.65	0.0033*		LC	39.65	<0.00001*
	AD	5.53	0.0187*		AD	25.09	<0.00001*
MA	YA	0.14	0.7068				
	MDA	7.55	0.006*				
	FI	20.12	<0.00001*				
	EC	0.01	0.9069				
	LC	15.82	0.0001*				
	AD	9.53	0.002*				

5.7.4 Population Comparisons by Site

Of the adult populations from specific archaeological sites, Wolverhampton was found to have the highest percentage of outlying measurements, followed by Hickleton and then St. Helen’s (see Table 5.52). Those sites with the lowest percentage of population outliers were from Hereford, Blackfriars, and York Minster. Chi-square tests indicate that each site had at least one significant difference with another population in the percentage of outlying measurements (see Tables 5.53 and AP 10.3). The Wolverhampton population differed significantly from all sites, except for Hickleton. Similarly, Hickleton differed from all but Wolverhampton. The percentage of outlying measurements from Hereford significantly differed from all sites, but Blackfriars, Towton, and York Minster. Towton had the lowest percentage of differences in outliers, only differing from the Hickleton and Wolverhampton populations.

Table 5.52: The number of outlying measurements among adults from specific archaeological sites.

Site	Outliers	Of	%
Blackfriars	10	1585	0.63
Chelsea	27	2602	1.04
Chichester	103	9216	1.12
Fishergate	101	10792	0.94
Hereford	33	5594	0.59
Hickleton	22	1094	2.01
St. Helen’s	116	9265	1.25
Towton	12	1286	0.93
Wharram Percy	93	8576	1.08
Wolverhampton	49	1925	2.55
York Minster	34	4634	0.74

Table 5.53: Chi-square tests comparing adults from specific archaeological sites. (*P<0.05, BF=Blackfriars, OCU=Chelsea, CH=Chichester, FG=Fishergate, HE=Hereford, HK=Hickleton, SH=St. Helen’s, TO=Towton, WP=Wharram Percy, HCW=Wolverhampton, and YM=York Minster).

Site		Chi-Square	P-Value	Site		Chi-Square	P-Value
BF	OCU	1.83	0.1762	OCU	BF	1.83	0.1762
	CH	3.04	0.0812		CH	0.12	0.7326
	FG	1.42	0.2328		FG	0.22	0.6353
	HE	0.03	0.8528		HE	4.82	0.0281*
	HK	10.17	0.0014*		HK	5.41	0.02*
	SH	4.46	0.0346*		SH	0.77	0.3814
	TO	0.84	0.3595		TO	0.09	0.7606
	WP	2.7	0.1007		WP	0.04	0.841
	HCW	18.68	<0.00001*		HCW	14.7	0.0001*
	YM	0.18	0.6755		YM	1.81	0.1786

Table 5.53: Continued.

Site		Chi-Square	P-Value
CH	BF	3.04	0.0812
	OCU	0.12	0.7326
	FG	1.59	0.2068
	HE	10.47	0.0012*
	HK	6.32	0.012*
	SH	0.7	0.4041
	TO	0.35	0.5555
	WP	0.04	0.8339
	HCW	23.26	<0.00001*
	YM	4.56	0.0328*
HE	BF	0.03	0.8528
	OCU	4.82	0.0281*
	CH	10.47	0.0012*
	FG	5.35	0.0207*
	HK	22.08	<0.00001*
	SH	15.12	0.0001*
	TO	1.87	0.1718
	WP	9.24	0.0024*
	HCW	49.22	<0.00001*
	YM	0.79	0.3727
SH	BF	4.46	0.0346*
	OCU	0.77	0.3814
	CH	0.7	0.4041
	FG	4.55	0.0328*
	HE	15.12	0.0001*
	HK	4.15	0.0416*
	TO	0.94	0.3329
	WP	1.06	0.3042
	HCW	17.67	<0.00001*
	YM	7.62	0.0058*
WP	BF	2.7	0.1007
	OCU	0.04	0.841
	CH	0.04	0.8339
	FG	1.04	0.3074
	HE	9.24	0.0024*
	HK	6.87	0.0088*
	SH	1.06	0.3042
	TO	0.24	0.6255
	HCW	24.26	<0.00001*
	YM	3.82	0.0508
YM	BF	0.18	0.6755
	OCU	1.81	0.1786
	CH	4.56	0.0328*
	FG	1.5	0.2203
	HE	0.79	0.3727
	HK	14.51	0.0001*
	SH	7.62	0.0058*
	TO	0.51	0.4749
	WP	3.82	0.0508
	HCW	34.58	<0.00001*

Site		Chi-Square	P-Value
FG	BF	1.42	0.2328
	OCU	0.22	0.6353
	CH	1.59	0.2068
	HE	5.35	0.0207*
	HK	10.89	0.001*
	SH	4.55	0.0328*
	TO	0	0.9923
	WP	1.04	0.3074
	HCW	35.07	<0.00001*
	YM	1.5	0.2203
HK	BF	10.17	0.0014*
	OCU	5.41	0.02*
	CH	6.32	0.012*
	FG	10.89	0.001*
	HE	22.08	<0.00001*
	SH	4.15	0.0416*
	TO	4.74	0.0296*
	WP	6.87	0.0088*
	HCW	0.83	0.3625
	YM	14.51	0.0001*
TO	BF	0.84	0.3595
	OCU	0.09	0.7606
	CH	0.35	0.5555
	FG	0	0.9923
	HE	1.87	0.1718
	HK	4.74	0.0296*
	SH	0.94	0.3329
	WP	0.24	0.6255
	HCW	10.39	0.0013*
	YM	0.51	0.4749
HCW	BF	18.68	<0.00001*
	OCU	14.7	0.0001*
	CH	23.26	<0.00001*
	FG	35.07	<0.00001*
	HE	49.22	<0.00001*
	HK	0.83	0.3625
	SH	17.67	<0.00001*
	TO	10.39	0.0013*
	WP	24.26	<0.00001*
	YM	34.58	<0.00001*

The subadult population from Blackfriars, Chichester, Fishergate, Hereford, Wolverhampton, and York Minster all had twice the percentage rate of population outliers than did the adult populations from these sites. The only site to have a smaller percentage of outliers was the subadult population from St. Helen's. Grubb's outlier tests indicate that Wolverhampton had the most significant differences in frequency of outlying subadult measurements, followed again by Hickleton (see Table 5.54). On the other hand, the subadult population with the smallest percentage of significant differences was York Minster, followed by St. Helen's and Blackfriars. Chi-square tests also indicate that each site had at least one significant difference with another population in the percentage of subadult outlying measurements (see Tables 5.55 and AP 10.4). Wolverhampton differed significantly from all other sites. York Minster differed from all sites, except for Blackfriars and St. Helen's. Finally, Blackfriars was found to differ only from the Wolverhampton population.

Table 5.54: The number of outlying measurements among subadults from specific archaeological sites.

	Outliers	Of	%
Blackfriars	5	423	1.18
Chichester	36	1490	2.42
Fishergate	32	1546	2.07
Hereford	22	1396	1.58
Hickleton	9	317	2.84
St. Helen's	23	2319	0.99
Wharram Percy	47	3972	1.18
Wolverhampton	49	600	8.17
York Minster	3	808	0.37

Table 5.55: Chi-square tests comparing subadults from specific archaeological sites. (*P<0.05, BF=Blackfriars, CH=Chichester, FG=Fishergate, HE=Hereford, HK=Hickleton, SH=St. Helen’s, WP=Wharram Percy, HCW=Wolverhampton, and YM=York Minster).

Site		Chi-Square	P-Value	Site		Chi-Square	P-Value
BF	CH	2.13	0.1288	CH	BF	2.13	0.1288
	FG	1.37	0.2411		FG	0.4	0.5285
	HE	0.34	0.5627		HE	2.48	0.1151
	HK	2.58	0.1085		HK	0.18	0.669
	SH	0.13	0.7233		SH	11.66	0.0006*
	WP	0	0.9982		WP	10.62	0.0011*
	HCW	22.06	<0.00001*		HCW	32.67	<0.00001*
	YM	2.78	0.0953		YM	12.77	0.0004*
FG	BF	1.37	0.2411	HE	BF	0.34	0.5627
	CH	0.4	0.5285		CH	2.48	0.1151
	HE	0.96	0.3278		FG	0.96	0.3278
	HK	0.69	0.4066		HK	2.22	0.1362
	SH	7.45	0.0063*		SH	2.42	0.1197
	WP	6	0.0143*		WP	1.22	0.2692
	HCW	40.01	<0.00001*		HCW	48.3	<0.00001*
	YM	10.2	0.014*		YM	6.49	0.0108*
HK	BF	2.58	0.1085	SH	BF	0.13	0.7233
	CH	0.18	0.669		CH	11.66	0.0006*
	FG	0.69	0.4066		FG	7.45	0.0063*
	HE	2.22	0.1362		HE	2.42	0.1197
	SH	7.64	0.0057*		HK	7.64	0.0057*
	WP	6	0.0143*		WP	0.48	0.4896
	HCW	8.9	0.0029*		HCW	93.31	<0.00001*
	YM	12.73	0.0004*		YM	2.76	0.0966
WP	BF	0	0.9982	HCW	BF	22.06	<0.00001*
	CH	10.62	0.0011*		CH	32.67	<0.00001*
	FG	6	0.0143*		FG	40.01	<0.00001*
	HE	1.22	0.2692		HE	48.3	<0.00001*
	HK	6	0.0143*		HK	8.9	0.0029*
	SH	0.48	0.4896		SH	93.31	<0.00001*
	HCW	112.94	<0.00001*		WP	112.94	<0.00001*
	YM	4.21	0.0402*		YM	54.11	<0.00001*
YM	BF	2.78	0.0953				
	CH	12.77	0.0004*				
	FG	10.2	0.014*				
	HE	6.49	0.0108*				
	HK	12.73	0.0004*				
	SH	2.76	0.0966				
	WP	4.21	0.0402*				
	HCW	54.11	<0.00001*				

5.7.5 Population Comparisons by Settlement Type

For adults, the settlement type that had the highest frequency of measurements with population outliers was the rural environment, while the urban population had the least (see Table 5.56). Chi-square tests indicate that there were no significant differences between the settlement types in the percentage of outliers (see Tables 5.57 and AP 10.5). Conversely, there were significant differences between subadult settlement types. The *leprosarium*/almshouse environment was found to have the most outlying measurements for subadult populations, while the rural environment the least (see Table 5.58). Subadults also differed significantly between the rural and the other two environments (see Tables 5.59 and AP 10.6). Subadults had proportionally twice as many population outliers as adults in both the urban and *leprosarium*/almshouse settings.

Table 5.56: The number of outlying measurements among adults from specific settlement types.

Settlement	Outliers	Of	%
Urban	343	33795	1.01
Rural	142	12272	1.16
Leprosarium/almshouse	103	9216	1.12

Table 5.57: Chi-square tests comparing adults from specific settlement types. (*P<0.05, U=Urban, R=Rural, and L/A=*Leprosarium*/almshouse).

Settlement		Chi-Square	P-Value
U	R	1.71	0.1911
	L/A	0.73	0.3935
R	U	1.71	0.1911
	L/A	0.07	0.7897
L/A	U	0.73	0.3935
	R	0.07	0.7897

Table 5.58: The number of outlying measurements among subadults from specific settlement types.

Settlement	Outliers	Of	%
Urban	144	7092	2.03
Rural	52	4370	1.19
Leprosarium/almshouse	36	1490	2.42

Table 5.59: Chi-square tests comparing subadults from specific settlement types. (*P<0.05, U=Urban, R=Rural, and L/A=*Leprosarium*/almshouse).

Settlement		Chi-Square	P-Value
U	R	11.01	0.0009*
	L/A	0.85	0.3557
R	U	11.01	0.0009*
	L/A	10.9	0.001*
L/A	U	0.85	0.3557
	R	10.9	0.001*

5.7.6 Population Comparisons by Period

There was a diachronic increase in the frequency of outlying measurements for both adult and subadult populations (see Tables 5.60 and 5.62). Post-medieval sites had the greatest percentage of population outliers, while the Anglo-Saxon period had the least. For all periods, subadult groups were found to have more outlying measurements than the adult groups, with subadults having proportionately almost three times as many population outliers than the adults from the post-Medieval period. Chi-square tests indicate that for both adults and subadults there was a significant difference in the percentage of outliers between the post-Medieval period and the other two periods (see Tables 5.61, 5.63 and AP 10.7-8). No significant differences were found between the Medieval and the Anglo-Saxon periods for either age group.

Table 5.60: The number of outlying measurements among adults from specific periods.

Period	Outliers	Of	%
Anglo-Saxon	32	4320	0.74
Medieval	404	39711	1.02
Post-Medieval	116	7091	1.64

Table 5.61: Chi-square tests comparing adults from specific periods. (*P<0.05, AS=Anglo-Saxon, M=Medieval, and PM=post-Medieval).

Period		Chi-Square	P-Value
AS	M	2.99	0.0839
	PM	16.41	0.0001*
M	AS	2.99	0.0839
	PM	20.04	<0.00001*
PM	AS	16.41	0.0001*
	M	20.04	<0.00001*

Table 5.62: The number of outlying measurements among subadult groups from specific periods.

Period	Outliers	Of	%
Anglo-Saxon	9	632	1.42
Medieval	118	7201	1.64
Post-Medieval	66	1392	4.74

Table 5.63: Chi-square tests comparing subadults from specific periods. (*P<0.05, AS=Anglo-Saxon, M=Medieval, and PM=post-Medieval).

Period		Chi-Square	P-Value
AS	M	0.16	0.6867
	PM	12.6	0.0004*
M	AS	0.16	0.6867
	PM	50.32	<0.00001*
PM	AS	12.6	0.0004*
	M	50.32	<0.00001*

Chapter Six

Discussion

6.1 Introduction

As presented in Chapter 5, the main aim of this study was to determine a baseline for normal levels of asymmetry within English skeletal populations. From this baseline, the current research aimed to examine the underlying contributing factors of differences in asymmetry and population outliers between sex, age, settlement type, and period and to assess the socio-economic status of the samples included. The following chapter firstly sets out the limitations of this research in Section 6.6.1. This is then followed by a review of the general considerations of asymmetry in the adult skeleton in Section 6.2 (subadults will be considered in greater depth in section 6.5) and a demonstration of the utility of asymmetry and population outliers in revealing congenital and developmental conditions within a population in Section 6.3. Section 6.4 discusses sexual dimorphism and Section 6.5 reviews asymmetry and age-at-death. The effect of urbanisation on asymmetry is discussed in Section 6.6, while Section 6.7 reveals diachronic changes in asymmetry. Lastly, Section 6.8 uses the results from inter-site comparisons to demonstrate socio-economic status differences in the expression of asymmetry.

6.1.1 *Limitations of the Research*

Although many of the traits produced statistically insignificant levels of asymmetry, this does not necessarily indicate that the sample was free of developmental instability, or that the individuals were not engaged in a strenuous or increased activity, but that it was merely undetectable in these skeletal populations using these methods (cf. Livshits and Kobyliansky 1991; Palmer 1994). Equally, the lack of fluctuating asymmetry in a sample does not necessarily indicate that there was an absence of environmental stress.

It could be that any single or short-term disruptions during development may not have been evident in the skeleton. The feedback processes that maintain the developmental stability of an individual could have had enough time and energy to correct for any insult or, alternatively, growth could have been suspended and then resumed once the stressor had passed. Likewise, as FA mainly occurs during ontogeny, many stressors that happen during adulthood are unlikely to influence the skeletal system to such a degree that they would be detectable, unless the stress was prolonged and/or of a great level. In juveniles, asymmetries may not have had sufficient time to accumulate before the individual died. Similarly, directional asymmetry may also be undetectable due to an individual's lack of strongly lateralised behaviour, late onset of biomechanical stress, and changes in activity patterns. Schell *et al.* (1985) also found that when right and left-handers were compared, right handed individuals had significant directional asymmetry but left-handers did not.

A population's average fluctuating or directional asymmetry may be masked by a combination of varying levels of individual asymmetries or by the presence of a few individuals with high values that are not outliers, but are on the upper limit of the 95% confidence level. One of the main problems facing researchers is the difficulty in separating out fluctuating asymmetry, directional asymmetry, and antisymmetry in their data, this especially being the case with directional and fluctuating asymmetry. Many studies concerning fluctuating asymmetry point out the risk of data being inflated due to the possible presence of directional asymmetry. Although some researchers suggest that fluctuating asymmetry data should be corrected for DA, no sufficient method has yet been proposed to remove DA from the data without confounding interpretations of developmental instability (Palmer and Strobeck 1986; Palmer *et al.* 1993; Palmer 1994;

Graham *et al.* 1998; Palmer and Strobeck 2003; Stige *et al.* 2006). Studies of DA, on the other hand, have largely ignored this conundrum as the majority do not account for the possible presence of FA within the data. As with fluctuating asymmetry, any results from tests for directional asymmetry may also be inflated by the existence of developmental instability and may not be solely due to changes in the biomechanical environment.

In the current study, some of the traits exhibited an admixture of asymmetries. The results indicate that although these measurements produced significant levels of DA, all of these traits also had a greater variation around the mean (R-L), indicating that fluctuating asymmetry is present (Palmer and Strobeck 2003). As there is a lack of an appropriate method to extract DA from FA, and vice versa, and because the level of DA in all measured traits in the current research were small enough not to confuse interpretations of FA, no corrections were made for DA in this research.

One of the main limitations to the current research is that the following interpretations of the results are based on an alpha level set at $p<0.05$. As multiple tests have been carried out there are increased risks that Type I errors were made (i.e. accepting a result as significant purely by chance) (Holm 1979; Rice 1989). However, there are also limitations to the use of the widely accepted Bonferroni adjustment. Recent criticism of the Bonferroni correction is that this procedure is too conservative when dealing with a large series of tests and although the formula ensures that Type I errors are not made, there is a high probability of making an increased number of Type II errors (i.e. rejecting a truly significant result) (Rice 1989; Bender and Langes 1998; Perneger 1998; Moran 2003; Nakagawa 2004). As this is the first detailed research to test levels of asymmetry on so many measurements on a range of English archaeological populations, the author based the following discussion and conclusions on a less conservative alpha level of 0.05 so as not to miss any significant results. If the alpha level is set so low due to the number of tests involved for such a complex study of asymmetry, it is likely that no such study would ever be published as few to no significant results would be found (Moran 2003; Nakagawa 2004). As of yet, there has not been a study that has tried to include such a comprehensive sample of measurements throughout the human skeleton for both directional and fluctuating asymmetry. However, as there is a high probability that some of the reported significant results are, in fact, due to a Type I error, therefore to ensure that the conclusions drawn from this research are sound, future research will have to be conducted to test these preliminary conclusions (Bender and Langes 1998). The following conclusions are also reinforced for outliers through an examination of individual outliers and their associated congenital and developmental condition (see Section 6.3). For all other tests, the results from the current research are reinforced by overall median asymmetry results and supported by a comparison of evidence that has already been inferred from osteological, archaeological, and historical sources.

Further support for the author's decision for using a $p<0.05$ threshold in the current research can be seen in the number of individuals rejected by the Bonferroni adjustment as being population outliers. After the Bonferroni adjustment was performed the author subsequently re-examined many of these rejected outliers and found that they, in fact, possessed outlying measurements and, in many cases, had noticeable congenital and developmental conditions, which made them candidates for removal as outliers from further asymmetry analysis (Palmer and Strobeck 2003). For instance, those individuals with measurements that were discounted as being population outliers after a Bonferroni adjustment included the individual York Minster 167 who was subsequently visually verified as possessing an extreme form of torticollis; Chichester 74 and Chichester109 (see Section 6.3.21 and supporting publications) who have extreme asymmetry in the cranium due to premature craniosynostosis and St. Helen's 5498 whose lower limb measurements were removed due to a deformity in one side causing extreme asymmetry.

A further limitation to this study is the low repeatability that existed for some of the measurements for both the author and for those who conducted the inter-observer error tests. Although intra-observer measurement error for all measurements included in the analysis was found not to be significant through both TEM and two-way ANOVA tests, some of the measurements had low repeatability. As the between-side variation was significantly higher than ME in all included traits, they warranted inclusion in this study. However, although there is of yet no standard acceptable level of ME5 repeatability (Palmer 2007 *pers. comm.*), the author suggests caution should be observed when interpreting the results from measurements with low repeatability and that more weight should be put on those measurements that had a high repeatability.

The nine measurements (not including the cranial measurements, see Chapter 5) that did not have acceptable levels of measurement error to asymmetry in the inter-observer error test were not removed from this study, as both the author's intra-observer error and the inter-observers' error for TEM were low for these measurements. All nine measurements were taken by the least experienced of the observers (Observers 3 and 4), except for TMLP, which was taken by Observers 2-4 and OCAH taken by Observer 2. All of these measurements were difficult to take due either to the unusual skeletal form or due to changes in the topography of the bone made by muscle attachments. To fully evaluate inter-observer error and to find if these nine measurements could be replicated under a more informed test, the inter-observer error test would need to be redone either with the same observers used in this study, who would be given a more in-depth explanation of how to take these measurements, or conducted by an observer who had a better understanding of both metric analysis and human skeletal anatomy. The results of the inter-observer error test not only identified those measurements that were difficult to obtain, but also those which could be taken with a high degree of accuracy, even if an observer did not have previous experience. These results also stress the importance that when conducting asymmetry studies, it is best that only one person who has experience of metrical analysis and the anatomy of human skeleton should take all the measurements throughout such research.

The last consideration is that of the limitations of working on archaeological material. Skeletons from an archaeological context are rarely complete and are usually fragmentary to some degree, limiting the number of measurements that can be collected. For instance, of the 1344 adult skeletons examined for this study, only 35 pelves were complete enough to take all 12 measurements and in only 57 crania could all 22 measurements be taken. Even with the more robust skeletal elements, less than half of the skeletons in this study had the bone present or was complete enough for all measurements to be taken. The most often present and complete adult elements were the tarsals (n=413), femora (n=372) and mandible (n=306). Other researchers have faced the same problem. For example, of the 326 skulls examined by Hoover and Matsumura (2008) for their study, only 49 met their criteria to be included. This limits the number of traits that can be included in an index and the statistical power of any tests. It also makes it all but impossible to have an index for a full skeleton. Furthermore, some of the sample populations included in this study were either incomplete to begin with or a small sub-sample of the excavated population. For instance, Hickleton only had 25 individuals, and time constraints and funding limited the overall number of individuals that could be included from Chelsea and Wharram Percy. Furthermore, there was also a male bias in many of these populations—including Chichester, Fishergate, York Minster, and Towton—due to the nature of the site.

6.2 General Considerations of Asymmetry

This is the first study to define a baseline for 'normal' levels of directional and fluctuating asymmetry by incorporating such a large sample size and trait selection, from both the cranium and post-cranium, and including both subadults and adults (see Chapter 5 Tables 5.7, 5.8, 5.31, and 5.32). The average normal levels of asymmetry for these adult English populations fall between a 95% confidence interval of -5.79 to 6.62% with a median of 0.36% for directional asymmetry and 0 to 6.53% for fluctuating asymmetry with a median of 1.99%. Subadults possessed similar levels with directional asymmetry ranging from -5.69 to 6.53% and median of 0.39%, and from 0 to 6.33% with a median of 2.04% for fluctuating asymmetry. Measurements that have the potential to be the most useful for detecting developmental instability and biomechanical stresses—i.e. measurements with the highest accuracy, lowest average levels of asymmetry, and lowest standard deviations—were the long bone maximum lengths, *os coxae* height and ischial length, and some of the cranial measurements (CLFMT, CNOR, CBZO CNMS, and CFMTN). Further, one measurement, humeral maximum length, was highlighted even after Bonferroni adjustments as being the most sensitive to comparative sample testing. Those measurements found to be the most variable and thus the least informative were mastoid process height, digastric groove length, and clavicular curvature depths.

Care should be taken when making generalisations about overall asymmetry levels within a population, and, these should be accompanied by a discussion of the results of individual traits. Similar to other studies (Van Valen 1962; Livshits *et al.* 1988; Livshits and Kobyliansky 1991; Clarke 1993; Pomiankowski 1997; Gangestad and Thornhill 1999; Badyaev *et al.* 2000; Kark 2001; Lazenby 2002; Leamy and Klingenberg 2005; Auerbach and Ruff 2006; DeLeon 2007; Sengupta and Karmakar 2007), it was found that asymmetry was trait-specific and was variable across, and within, all skeletal elements. It has previously been reported that, for fluctuating asymmetry, between side differences are generally less than 5% (Palmer 1994), however, this was not the case for many of the measurements taken during this research. When calculating each measurement's range of fluctuating asymmetry and those measurements falling within two standard deviations of the mean for each measurement, only 67% of the adult and 64% of subadult measurements in this research had average asymmetry ranges of less than 0-5%. Sixteen percent of the adult traits had asymmetry ranges reaching 10% or more. For directional asymmetry, 79% of adult and 77% of subadult measurements had average ranges of less than 5% in both directions, with 17% reaching 10% or more.

The large differences in some traits' normal asymmetry ranges also bring into question whether or not it is suitable to use asymmetry indices. In this study, asymmetry levels can range from anywhere to as high as -30.72 to 30.92% (mastoid process height) for adults and -25.59 to 26.89% (maximum depth of the lateral curve of the clavicle) for subadults and as low as -1.75 to 1.37% (*os coxae* height) for adults and -1.81 to 1.43%

(femoral maximum length) for subadults. Fluctuating asymmetry levels can range from as high as 0 to 31.76% (mastoid process height) for adults and 0 to 25.75% (maximum depth of the lateral curve of the clavicle) for subadults and as low as 0 to 1.7% (*os coxae* height) for adults and from 0 to 1.72% (femoral maximum length) for subadults. It is possible that there are traits with even higher or lower trait-specific ranges that were not included in this study. If an index is used, it should consist of a combination of traits with similar means and standard deviations. Therefore, in this study inferences based on indices alone are not given as much weight if they could not be accompanied by a discussion of single measurements result.

6.2.1 Asymmetry of the Cranium

Similar to the findings of other studies, the cranium was found to be normally asymmetric and predominantly right-sided (Woo 1931; Trinkaus 1978; Skinner *et al.* 1989; Cohen 1995). Tests for directional asymmetry in the cranium ascertained that many of the traits had a significant directionality to the right side. Of the measured cranial traits, only eight did not demonstrate significant DA (COBH, CNOR, CFMTNS, CMAH, CEMCMIS, CMPH, COCL, and COPO), while the remaining 14 traits tested significantly for DA ($P<0.001$, except CDGL where $P<0.005$). Of those traits that exhibited significant DA only two, CDGL and CBAPO, were left-side dominant. These findings are comparable to a study conducted by Hershkovitz *et al*. (1992) on craniofacial asymmetry of Bedouin adults. The majority of their traits tested significantly for DA and right-side dominance. The current study seems to further support the conclusion that the human cranium is by nature asymmetric, which could be influenced by underlying cerebral asymmetries (Chiu and Damasio 1980; Pirttiniemi and Kantomaa 1992; Steele 1998; Good *et al*. 2001; Hershkovitz *et al*. 1992; Woo

1931). However, many of the proponents of the hypothesis that lateralisation of the cranium is caused by cerebral asymmetries do not take into consideration the existence of congenital and developmental abnormalities.

When actual counts of the occurrence of right- and left-side dominance with in a population were evaluated, regardless of the degree of asymmetry, the overall pattern of cranial asymmetry becomes more complicated. As Sommer *et al*. (2006) argue, cranial asymmetries have multiple causes of both intrinsic and extrinsic factors. Six adult measurements were left-sided: two from the viscerocranium (CNOR and CMAH) and the remaining in the cranial base (CDGL, COCL, COPO, and CBAPO). Similarly, five subadult measurements were left-side dominant, three in the viscerocranium (CFMTN, CMAH, and CECMIS) and two in the cranial base (CDGL and COCL). The adult mandible was also significantly left-side dominant in length and right-side dominant in ramus height. This patterning of asymmetries is indicative of a degree of facial asymmetry and torsion of the sagittal axis and may be evidence that there is a normal degree of torticollis or positional plagiocephaly within the population (see Section 6.3).

6.2.2 Asymmetry of the Upper limb

The results of this study concur with previous research that there is a general trend for the majority of the population to be right-side dominant in the upper limb (Schultz 1937; Latimer and Lowrance 1965; Pande and Singh 1971; Ruff and Jones 1981; Stirland 1993b; Huggare and Houghton 1995; Steele and Mays 1995; Sansibano-Collilieux and Morello 1996; Wilczak 1998; Tanaka 1999; Čuk *et al.* 2001; Auerbach and Ruff 2006; Auerbach and Raxter 2008; Kujanová *et al.* 2008). All measurements were found to be significantly right-sided, apart from the subadult measurements SGB, RGH, RMLD, and the metacarpal lengths. Levels of directional and fluctuating asymmetry in upper limb measurements and indices were all higher than that of the lower limb. The humerus was the most asymmetric bone in the upper limb in length, while the radius had the most asymmetry in maximum diameter at midshaft. The humeral index was found have the greatest median DA, while the clavicular index had the least. The clavicular index had the most FA, while the metacarpal index had the least. This indicates that although there is an amount of fluctuating asymmetry in the humerus, it is affected more by biomechanical stimuli than developmental instability. The opposite seems to be true for the clavicle. The clavicle is the first bone in the upper limb to form primary ossification centres at about 5 weeks prenatal and the last to fuse at 29+ years (Scheuer and Black 2000), allowing for a greater period for the accumulation of fluctuating asymmetry.

Similar to Steele and Mays (1995) who found humeral length to be right-side dominant in 77% of the Wharram Percy population, with 15% left-side dominant, the current study found that for all included populations the prevalence was 78% right-sided and 13% left-side dominant. This frequency is consistent with prevalence studies of handedness based on strength tests, suggesting that humeral length asymmetry is responsive to the biomechanical environment. On the other hand, this patterning does not extend to the forearm and hands. Only 64% of the population were right-sided and 20% left-sided in the radius, 67% right-sided and 22% left-sided for the ulna, and only 54-59% right-sided and 35-42% left-sided for the metacarpals. This suggests that handedness has a greater effect on the arm than the forearm, while the hand is not as directionally affected. However, when testing the extent of directional asymmetry in the hands it was found to be significantly right-sided in all five adult metacarpals ($p<0.001$), suggesting that right-side dominant individuals are more asymmetric than their left-sided counterparts. This is similar to Plato *et al.*'s (1980) study that found significant asymmetry in width, length, and cortical area of MC2 in right-handers but not in left-handed individuals. A mixture of fluctuating and directional asymmetry also existed in the upper limb. This study is in agreement with Mays' (2002) study that concludes that fluctuating asymmetry may be obscuring any activity-related directionality. The converse may also be suggested, in that directional asymmetry may be obscuring developmental disturbances.

The clavicle had the most complex patterns of directional asymmetry in the upper limb. Similar to the results of previous studies (Shultz 1937; Huggare and Houghton 1995; Mays *et al.* 1999; Steele 2000b; Auerbach and Raxter 2008; Kujanová *et al.* 2008), the right clavicular diaphysis was found to be significantly shorter and more robust. The clavicle was also more robust at the sternal and acromial ends on the right side. It has been suggested that the shorter length and increased diaphyseal robustness are in response to increased loading of the dominant side (Mays *et al.* 1999). It could also be that this right side asymmetry of the clavicle is a reflection of underlying natural asymmetrical layout of the organs in humans (*situs solitus*). The right clavicle also had a deeper lateral curvature than the left side (although this curvature was not significant), while the left side possessed significant medial curvature for the adult population. This is converse to what Mays *et al.* (1999) found when looking at solely the Wharram Percy sample. Their study indicated a left-sided lateral curvature and an insignificant directionality in medial curvature of the left side. Although not significant, the increased lateral curvature on the right side found in the current study may be a reflection of a need for a larger area of attachment for *M. deltoideus* on the dominant side. The greater lateral curvature could also be a response to a greater range of motion in the shoulder girdle on the right side (Iannotti and Williams 2007).

6.2.3 Asymmetry of the Pelvis

The current study found the sacral alae to be significantly left-sided, similar to Plochocki's (2002) findings. However, unlike Plochocki's (2002) study, the current research found that the auricular surfaces were right-side dominant. There is a complex loading and strain transition through the sacrum and pelvis during movement from the upper and lower body. The sacrum transmits axial load from the upper body over the sacral alae and sacroiliac joint to the *ossa coxae* and then lower limbs. The sacrum is also subject to shear and torsional forces from the lower limbs through the asymmetric gait cycle. During the gait cycle distribution of loading stress in the pelvis is greatest at the acetabulum moving to the sacroiliac joint and pubic symphysis (Dalstra and Huiskes 1995; Stone 1999; McGrath 2004). If asymmetric loading of the upper limb due to hand preference is the cause of the sacral asymmetry, then it is expected that it should affect the contralateral side of the sacral alae (Plochocki 2002). If sacral asymmetry is caused by asymmetrical movement of the lower limb during locomotion, then it is expected that asymmetry will be consistent with lower limb asymmetry on the same side. As upper limb asymmetry favoured the right side and femoral length was left-side dominant, the current study supports both of these relationships. It is suspected that sacral asymmetry can be attributed to both asymmetric loading of the upper limb and asymmetric movement of the lower limbs and hence can be related to handedness and asymmetric leg lengths and gait. However, as levels of fluctuating asymmetry in the sacrum were higher than all other whole skeletal elements, except for the clavicle, it is also suspected that sacral asymmetry is highly influenced by developmental instability from environmental stresses other than biomechanical ones.

The *ossa coxae* were found to favour the right side in all measurements but pubis length, which was left-side dominant, while *os coxae* height and breadth favoured symmetry. The selection for symmetry in the *os coxae* height and breadth could be evidence of the need for the body to maintain symmetry for bipedal locomotion. Symmetry in these structures could also be due to the comparatively less strain distribution in this area during loading (Dalstra and Huiskes 1995), while the directionally left-sided pubis is a reflection of the transmission of greater strain forces on the left side due to either the right-side dominance of the upper limb or left-side dominance of the alae and femora.

6.2.4 Asymmetry of the Lower Limb

The lower limb exhibited lower median levels of both fluctuating and directional asymmetry than the cranium, upper limbs and pelvis. There was a small but significant left side bias for femoral length and maximum diaphyseal diameter measurements. This left-side dominance of the femur is consistent with findings from previous research (Schultz 1937; Latimer and Lowrance 1965; Ruff and Hayes 1983; Huggare and Houghton 1995; Čuk *et al.* 2001; Auerbach and Ruff 2006; Kujanová *et al.* 2008). Unlike other researchers (Latimer and Lowrance 1965; Bagnall *et al*. 1982; Ruff and Hayes 1983), symmetry was found in tibial length, tibial maximum diameter at the nutrient foramen, and in all of the tarsal measurements. Although the lower limb was found to have significant levels of directional asymmetry for all but eight measurements (FIMS, FMLP, TML, TXNF, CZL, TZB, MT3L, and MT4L), all but two measurements had medians less than 0.4% (except for TINF at 1.02% and CZB at 0.51%) and 15 measurements were symmetrical (FIMS, FIST, FEB, FLE, FMLP, TML, TMLP, TMC, all tarsal measurements, and MT3L). Similar to the upper limbs, the highest levels of fluctuating asymmetry were located in diaphyseal measurements, with the least FA found in the lengths of the femur, tibia, and metatarsals. As growth in the length of the long bones is predominantly static after epiphyseal fusion, while the diaphysis continues to adapt (Ruff and Jones 1981; Steele and Mays 1995; Čuk *et al.* 2001), this high diaphyseal FA may be used to infer the adult population's ability to buffer against environmental stress after ontogeny.

It was found that the lower limb elements showed a trend for selecting for stability, i.e. symmetry. In traits in which symmetry is essential for the normal functioning of an individual, more resources are used to ensure its developmental stability (i.e. reducing levels of asymmetry) at the expense of those traits that can function without symmetry, which will have, as a result, higher levels of asymmetry (Clarke 1993; Møller and Swaddle 1997; Pomiankowski 1997). Increased symmetry in the femora and tibiae compared with the upper limb elements could be due to the structural need for these elements to be of equal size to provide support of the body. As the lower limbs are relied upon for stabilization and locomotion and have relatively equal mechanical loads on both sides, symmetry is essential, whereas the upper limb is not constrained and is influenced by a variety of different mechanical loads affecting each side differently, hence the greater asymmetry (Plockocki 2004; Auerbach and Ruff 2006). With the need for stability in the bipedal stance and locomotor function of the human body, the body's self-correcting mechanisms will choose to expend more energy in the lower limbs to maintain its optimal homeostasis at the expense of the skull and upper limbs when under stress.

6.3 Asymmetry applied to the Identification of Congenital and Developmental Conditions

6.3.1 Introduction

This is the first research to demonstrate that asymmetric population outliers can be used to measure developmental instability within archaeological populations. Although most researchers remove outliers from their data, as Palmer (1994) suggests, the results of this study indicate that a complete disregard for their existence will mask any real population developmental stability. By the complete removal of outliers from studies of asymmetry, valuable information is lost. While it is agreed that population outliers should be removed from the actual calculation of population levels of asymmetry, it is suggested that these population outliers, by their very nature, provide valuable insight not only into population-level developmental instability as will be demonstrated in the following sections, but also in the detection of an individual's inability to buffer from environmental and genetic stress.

Previous research conducted by the author indicated that through a closer examination of individuals with outlying measurements and/or extreme asymmetry (i.e. lying outside the 95% confidence interval), it was apparent that while a few individual asymmetries could be due other pathological processes (or of an unknown origin), many of the outlying measurements upon a second examination were found to have been taken from individuals who exhibited some form of congenital/developmental abnormality (see supporting material) (Storm and Knüsel 2005, Storm 2006, 2007, 2008). As the “development [of an individual] has to be disrupted to a reasonably major degree before these phenotypes arise” (Møller and Swaddle 1997: 7), an increase in the prevalence of congenital conditions is also indicative of high levels of environmental stress (Parsons, 1990; Møller and Swaddle 1997; Thornhill and Møller 1997).

The following case studies and supporting documents provide a demonstration of the validity of using asymmetry outliers and increases in asymmetry from the population norm to uncover congenital and developmental conditions. As it is the aim of this section to simply demonstrate the usefulness of fluctuating asymmetry and population outliers, a full review of all of the congenital conditions found within these populations and specific diagnoses are not made at this time. Their analysis will hopefully lead to future research.

6.3.2 Case studies

6.3.2.1 Premature Craniosynostosis in Chichester

Craniosynostosis is the premature closure of the cranial sutures, which results in cranial deformation and asymmetry caused by compensational changes in cranial structure due to the continued growth of the brain. The condition occurs during early stages of ontogeny up until the brain reaches 90% of its adult size (Cohen 1986; Kabbani and Raghuveer 2004). Today, even with the advances in medical practice, premature craniosynostosis affects an average of 3 in 10,000 births worldwide (World Health Organisation 2002; Mossey and Castilla 2003). Table 6.1 summarises the normal closure times of each suture and the distinct shape created by premature closure. In archaeological material premature craniosynostosis is difficult to determine in an adult sample. It is suggested that by recording asymmetries and comparing these to a baseline of normal asymmetry values, it is possible to detect compensational changes in growth due to a synostosis during early ontogeny and to provide evidence of non age-related closures.

Table 6.1: Normal closure times of each suture and the distinct shape created by premature closure (Kokich 1986; Jimenez *et al.* 1994; Aviv *et al.* 2001).

Suture	Age Closure Typically Commences	Skull Shape Associated with Early Closure
Metopic	9 months-2 years	Trigonocephaly
Coronal	24	Unilateral: Plagiocephaly Bilateral: Brachycephaly
Sagittal	22	Scaphocephaly
Lambdoid	26	Unilateral: Plagiocephaly Bilateral: Brachycephaly
Squamosal	35-39	Plagiocephaly
Occipitomastoid	26-30	Plagiocephaly

Within the Chichester population, of the available 108 crania complete enough for observation, there were eight individuals with clear cases of craniosynostosis that exhibited high levels of asymmetry in the cranium. This provides a very high prevalence of 7% of the observable population. Of these, at least four individuals, burials 38, 73 (see Figure 6.1), 109, and 374, are of special note as they would have had noticeable deformity, which may have affected their social interactions. A further six may have suffered early suture closure and asymmetries but they were discounted in this assessment due to the advanced age of the individuals and the lack of clear compensational asymmetry (Storm 2007, 2008). See the supporting publications for a full description and discussion of each of these individuals.

Figure 6.1: Chichester 73 with premature craniosynostosis of the left side coronal suture.

6.3.2.2 Torticollis and Positional/Deformational Plagiocephaly

Torticollis is the abnormal lateral positioning of the neck with a degree of head rotation and tilt. Today, even with advances in medical knowledge and better childbirth practices, as many as 18% of all children are born with a form of torticollis. It is proposed that the prevalence of torticollis would have been higher in the past populations. This condition is usually indicative of an underlying congenital, developmental or pathological disorder, or it could be a response to a traumatic injury during birth or in ontogeny (Skinner *et al* 1989; Karmel-Ross 1997; Cheng *et al* 2000; Freed and Coulter-O'Berry 2004; Storm 2008). Skeletal evidence of torticollis includes flattening of the frontal and occipital bones, torsion of the sagittal axis, facial asymmetry, dropped orbit, one enlarged and one atrophied mastoid process, a recessed malar, posteriorly placed ipsilateral ear, bulging of the occipital on the affected side, cervical scoliosis, degenerative changes in the cervical vertebrae, mandibular asymmetry, changes to the clavicle and post-cranial asymmetry (Skinner *et al* 1989; Douglas 1991; Storm and Knüsel 2000; Knüsel 2002; Yu *et al* 2004; Storm 2008).

A high occurrence of torticollis was noted within the populations included in this research. The extent to which it is expressed is variable, but many of the individuals would have had noticeable head tilt and rotation. For instance, the Chichester population possessed a relatively high prevalence of torticollis; at least 10% (23 adults) has a degree of abnormal torsion of the cranium (see Storm 2008 for a further discussion). A rough examination of the York Minster sample indicated a prevalence of torticollis of at least 17.2% (21 individuals). All of these individuals have at least four or more of asymmetries and shape changes that are typical of torticollis. This included a single cranium of an Anglo-Saxon middle adult male (from context 215) who had an outlying measurement of COBB (FA8=0.058, T_G=3.1767, $p<0.05$), CNOR (FA8=0.052, T_G =4.573, $p<0.01$), and CFMTN (FA8=0.061, T_G =5.224, $p<0.01$). He also had three measurements that fell outside the normal range of fluctuating asymmetry: CMPH (FA8=0.496), CDGL (FA8=0.292), and COCL (FA8=0.118). Indications of torticollis included an enlarged left mastoid process and right occipital condyle, a flattened right occipital, torsion of the sagittal axis, and a dropped orbit (see Figure 6.2).

Figure 6.2: Individual from York Minster exhibiting muscular torticollis.

Positional/deformational plagiocephaly is the asymmetric deformation of the skull, where one side is flattened causing the skull to be oblique. This deformation has been related to positioning of the head during early developmental, torticollis, and trauma during the birth process. The expressed asymmetry may also be indicative of an infant's preference in sleeping position, which can continue into adulthood (Boere-Bonnekamp and van der Linden-Kuiper 2001). An excellent illustration of positional asymmetry comes from studies of head shape since launch of the 'Back to Sleep' campaign in the 1990s. This multi-national campaign suggests that to help reduce the risk of sudden infant death syndrome (SIDS) an infant should be placed to sleep on his/her back. There has since been an exponential increase in the number of cases of deformational plagiocephaly (Biggs 2004; Sommer *et al*. 2006). One study of infant sleep position preference found that of the 7609 infants studied, 8.2% possessed preferential head position and, as a result, had plagiocephaly; of these 68% preferred the right side and 27% the left. A little under a half of these infants still had noticeable flattening at 2-3 years of age (Boere-Bonnekamp and van der Linden-Kuiper 2001).

An example of positional plagiocephaly in the samples from the current study comes from the Chichester population. Although this individual only had one cranial measurement that fell outside the 95% confidence range of normal asymmetry (CBAST FA8=0.036), it did exhibit high levels of cranial asymmetry suggestive of slight plagiocephaly. Chichester 267 is a middle adult male (see Figure 6.3) having cranial asymmetries that include a broader right orbit (FA8=0.034), a larger left occipital condyle (FA8=0.11), a left parietal that is larger diagonally by 5mm (FA8=0.036) and a viscerocranium that is rotated to the left by 4mm (FA8=0.033). The occipital has a longer right branch of the lambdoid suture by 2.4mm (FA8=0.028). Further, the curvature of the left parietal is more steeply sloping from the sagittal suture, the right mastoid process is more anteriorly placed, the left malar is positioned more superiorly than the opposite, and the left occipital condyle is positioned more inferiorly than its homologue on the left. These asymmetries, along with an unusual surface contour, flattening of the parietals posteriorly, evidence of healed cranial lesions posteriorly (possible ulcerations), and plagiocephaly could be indicative of positional head deformity with associated torticollis (Storm 2008).

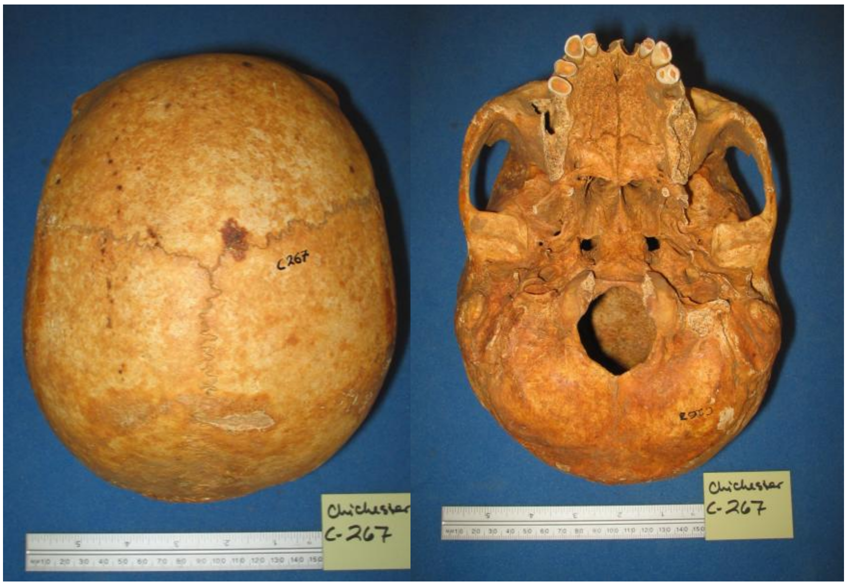

Figure 6.3: Chichester 267 exhibiting slight positional plagiocephaly.

6.3.2.3 Hereford 3116

Hereford 3116 is a young adult male who exhibited cranial and post-cranial asymmetry (see figure 6.4). This individual was found to have outlying measurements for CECMIS, CNMS, MAL, and MRH. He was also had six measurements that fell outside the normal fluctuating asymmetry range (see table 6.2). The skull exhibited evidence of torticollis: enlarged mastoid processes (especially on the left side), asymmetrical development of the nuchal muscles to the right, occipital protuberance shifted to the right, occipital flattening on the right, deviation of the viscerocranium to the left, and mandibular asymmetry. Although the right mastoid had postmortem damage, its height would not have been much over 33.97 mm, while the left side was 40.26mm. Other observations in the cranium included a prominent forehead with large asymmetrical bossing (right larger), flattening of the viscerocranium, small orbits compared to overall to cranial size, an over-bite, and occipital muscle attachments that seemed to indicate increased biomechanical stress. Post-cranial changes included vertebral asymmetry especially in the fifth lumbar, abnormal shape in the vertebral ends of the ribs, accessory vertebral facets on the ribs, deep cortical defects for the costoclavicular ligament, sternal asymmetry at rib and clavicular articulations, articular changes in the metatarsals, and structural changes to the distal tibia with deeper grooves for *M. tibialis posterior* and *M. tibialis anterior*. A tentative diagnosis would be that this individual suffered from a congenital syndrome, possibly Down's syndrome with associated club feet. However, more extensive reconstruction and a more in-depth examination are needed.

Table 6.2: Outlying and extreme measurements of Hereford 3116.

Measurement	FA8	T_G	p<
CECMIS	0.096	3.86	0.05
CFMTB	0.035		
CNMS	0.063	4.374	0.01
CLFMT	0.025		
CLAST	0.059		
MAL	0.109	9.283	0.01
MRH	0.182	8.9021	0.01
MXRB	0.075		
TXNF	0.071		
TINF	0.089		

Figure 6.4: Hereford 3316 exhibiting extreme cranial asymmetry.

6.3.2.4 Chelsea 258

Chelsea 258 is a young adult male (a Mr. T. Robson or Marson) (Cowie *et al.* 2008), with high levels of fluctuating asymmetry in both the cranium and post-cranial skeleton. This individual was found only to be an outlier for MC2L (FA8=0.059, T_G=6.023, p<0.01), however, 18 measurements fell outside the 95% confidence level (see Table 6.3). This individual exhibits multiple cranial changes: a smaller left orbit that is dropped and has deformation of the inferior margin, a larger right malar, a larger left mastoid process, longer right parietal, rotation of the sagittal axis, a larger right occipital, a long cranial base, evident bossing of the frontal, extreme mandibular asymmetry, and dental enamel hypoplasia (see Figure 6.5). Post-cranial changes include: a shorter and more gracile left upper limb, vertebral asymmetry suggestive of scoliosis (see Figure 6.5), a smaller right *os coxae*, anterior articular modifications of the femoral head, and medio-lateral bowing of the tibiae suggestive of healed rickets, as well as a relatively short stature (158cm) based on femoral length. Without further examination, only a diagnosis of a non-specific congenital condition can be made at this time.

Table 6.3: Measurements expressing extreme asymmetry in Chelsea 258. (*Population outlier T_G=6.023, p<0.1).

Measurement	FA8	Measurement	FA8
COBB	0.053	UXMS	0.123
CNOR	0.035	MC2L*	0.059
CFMTN	0.038	MC4L	0.039
CFMTNS	0.035	MC5L	0.052
MRH	0.047	TXNF	0.093
MXRB	0.072	TINF	0.091
MIRB	0.102	TMC	0.05
CVWA	0.148	TLC	0.051
SGL	0.085	TZB	0.057
HML	0.032		


Figure 6.5: Chelsea 248 exhibiting extreme cranial and post-cranial asymmetry.

6.4 Sexual Dimorphism and Asymmetry

Females and males had almost identical levels of fluctuating asymmetry for both medians and 95% confidence interval ranges, although females had slightly higher directional asymmetry. There were no significant differences in population outliers between the sexes, although males had more outlying measurements than females. For both DA and FA, sex was found to have significant differences in 19 measurements and six indices. However, only roughly half of these significantly differed for both asymmetry types (measurements: HML, HXMS, HIMS, HDT, HGT, RML, UML, UPL, TMLP; and indices: humerus, upper long bone length, mid shaft, upper limb midshafts). Significant differences in directional asymmetry between the sexes were almost solely limited to the upper limb; CFMTN, TMLP, MT1, and the mandibular index being the only exceptions. Male clavicular midshafts were significantly higher in DA (similar to Auerbach and Raxter's (2008) findings); and males and females differed in the direction of asymmetry in minimum midshaft diameter and lateral curvature. Unlike females, males were found not to have significant levels of DA in either clavicular minimum midshaft diameter or lateral curvature. This is contrary to Mays *et al.*'s (1999) study where the authors found a lack of overall sexual dimorphism in the clavicle and noted that males, not females, had a greater lateral curvature. The current research revealed males were significantly more right-side dominant for humeral diaphyseal midshaft measurements, measurements at areas of muscle attachment, and articular measurements; while females were significantly greater in upper limb lengths, radial head, and ulnar midshaft diameter. This is consistent with the findings of previous studies (Schultz 1937; Ruff and Jones 1981; Steele 2000b; Auerbach and Ruff 2006; Sladek *et al.* 2007; Kujanová *et al.*2008). Females had significant levels of DA in all metacarpal measurements, but males did not. Females also were significantly more right-side dominant in three of the metacarpal lengths (MC2, 3 and 5) when compared with males. This is opposite results to that of Mays' (2002) study of the cross-section and length of MC2, where females did not exhibit significant DA while the males did.

Significant differences between the sexes in fluctuating asymmetry were more widely distributed throughout the skeleton than those for DA, although there is a similar predominance for upper limb asymmetry. Of the significant differences, females were found to have more traits with higher levels of FA than males. As in DA, males were greater in FA for diaphyseal measurements, areas of muscle attachments, and articular measurements in the humerus; whereas females had greater FA in the length measurements of the upper limb. Of the remaining significant differences, females possessed a higher degree of FA than males, except in CMSAST and CNMS, indicating that females were under greater amounts of environmental stress or were less able to buffer from environmental insults.

The similar differences in fluctuating and directional asymmetry found between males and females in the upper limb raises the question: are these differences a reflection of sexual division of labour in past populations (resulting in directional asymmetry) or are they a reflection of some disadvantage or environmental stimuli affecting only females (resulting in fluctuating asymmetry)? In general, differences in length asymmetry would have been set before adulthood, as bone does not increase in length after the fusion of the epiphyses, but mid-shaft dimensions continue to adapt throughout adulthood (Pfeifer 1980; Steele and Mays 1995). This would indicate that females were subject to greater exogenous and/or endogenous stress during ontogeny, while males were affected by such factors over a longer period mainly during adulthood.

If the differences in asymmetry between the sexes were of a reflection of biomechanical adaptation, then these results suggest that males were engaged in activities that required a greater amount of repetitive movement and greater upper arm strength on the right side, while females had greater loading of their right forearms. It can also be inferred from length differences that this division of loading patterns would have occurred at an early age. However, these differences could be attributed to numerous activities;

therefore, it is not possible to make inferences about which specific activities males and females were engaged in, which were responsible for the directionality of these measurements (cf. Trinkaus *et al.* 1994). Further research would have to be completed, which would incorporate results from the analysis of other activity related changes to the skeleton (e.g. cross-sectional analysis and enthesopathy).

Some broad inferences of activity and their reflected asymmetry can be achieved through a further division of sex by period and settlement type and then by a comparison of these results to historic accounts of activity (see Table 6.4 and electronic appendix). Of those measurements found to significantly differ between the sexes in DA, the majority occurred during the Medieval period. Similar to the overall patterning of asymmetry differences between the sexes, males and females from the medieval sample differed in 14 measurements (all but two being in the upper-limb) and five indices. During the Anglo-Saxon period only three measurements significantly differed between the sexes, while the post-medieval sample had nine measurements and two indices that significant differed between males and females. The majority of differences between the sexes during the post-Medieval period occurred in the cranium and mandible, with only four occurring in the upper limb. Rural populations had more significant differences, with 17 measurements and five indices differing, while urban males and females significantly differed in 14 measurements and six indices.

Table 6.4: Lists of measurements and indices with significant differences in directional asymmetry between males and females grouped by period and settlement type. (M/R=Males are more right-side dominant than females, M/L=Males more left-side dominant, F/R=Females are more right-side dominant than males, F/L=Females are more left-side dominant, CD=Change of directionality).

Anglo-Saxon	Medieval	Post-Medieval	Rural	Urban
MXRB F/R	MXRB M/R	COBH CD	CFMTN F/L	CMAH F/L
HXMS M/R	CVIMS F/L	CMSAST F/R	CBPO F/R	COPO F/L
UPL F/R	HML F/R	CNMS	CVXMS M/R	HML F/R
	HXMS M/R	CBPO F/R	HML F/R	HXMS M/R
	HIMS M/R	MXRB CD	HXMS M/R	HIMS M/R
	HDT M/R	CVXMS M/R	HIMS M/R	HDT M/R
	HGT M/R	HXMS M/R	HDT M/R	HGT M/R
	RML F/R	UML F/R	HSIH M/R	RML F/R
	RGH M/R	UPL F/R	HAPH M/R	RXMS M/R
	UML F/R	Midshafts M/R	HGT M/R	UML F/R
	UPL F/R	Upper limb midshafts M/R	RML F/R	UPL F/R
	UXMS F/R		UML F/R	UXMS F/R
	MC3L F/R		UPL F/R	MC3L F/R
	TMLP		UIMS M/R	SZAW M/L
	Mandible CD		MC2L F/R	Scapula F/R
	Humerus M/R		MC5L F/R	Humerus M/R
	Metacarpals F/R		TMC CD	Metacarpals F/R
	Os Coxae F/R		Humerus M/R	Upper long bone lengths F/R
	Upper long bone lengths F/R		Upper long bone lengths F/R	Midshafts M/R
			Midshafts M/R	Hip F/R
			Upper limb midshafts M/R	
			Knee M/R	

These results could indicate that during the Medieval period there was a greater sexual division of labour than during the other periods, where there was a less marked difference between settlement types. As the majority of asymmetry would have accumulated during ontogeny, we need to first make the presumption that boys would have been engaged in the more physically demanding occupations of their fathers and girls would have helped their mothers on the domestic scene (Finucane 2000) and, thus, the division of labour would mirror that of the parents. In medieval rural England, according to a study of accidental deaths, the majority of women's work concerned the domestic sphere (Hanawalt 1986), although they were also documented to have worked in the fields and be employed in similar manual labour as men at certain times of the year (e.g. reaping, binding, thatching) (Jewell 1996; Schaus 2006). There was a less marked division of labour in urban centres as, in many cases, the workshop was the home and women would have been engaged in their husbands' craft (Power 1995). When employed outside the home, women were more apt to have less prestigious and lower paying occupations (Jewell 1996). In the post-Medieval period, with the move away from agricultural work and greater percentage of the population living in urban centres, both males and females would have been engaged in similar occupations with the transition to industrialised factory work. However, it has been found that those individuals who were employed under the age of 15 years were twice as likely to be boys. Furthermore, the majority of women were still in subordinate positions and were commonly known to give up work once married, as a woman's place was still seen to be in the domestic sphere. The lesser role of women in the workforce can be seen in the cotton factories and that manual workers were more likely to be women, while higher paid overseers and mechanics were men. Women were also more likely to have less physically demanding occupations than males. The majority of women were employed in the textile industry, while men were in more diverse occupations, including the coal, steel, and iron industries (McCord 1991; Prest 1998). Woman's work in specialised occupations or in the domestic sphere would have been physically demanding (Jewell 1996), but may not have required them to utilise as much upper arm strength as men. The lack of sexual division of labour during the Anglo-Saxon period suggests that females may have been employed in similar manual labour as men for longer stretches of time than that of women in the following periods, due to the reliance on an almost purely agricultural based economy. However, the small size of the sample from the Anglo-Saxon period may be obscuring these results.

If the significant sex differences found in the current research are a reflection of the historical record and ontogenetic biomechanical adaptations, then it would be expected that males would have had higher levels of directional asymmetry in all measurements, in all periods. However, apart from significant differences in humeral diaphysis, humeral articular dimensions, and clavicular midshaft measurements, this was not the case, as females had higher levels of DA. These findings may suggest that males were engaged in a greater number of bimanual activities, while females were more often employed in unilateral tasks. It could also be that long bone and metacarpal lengths may not be solely influenced by biomechanical stress. The differences in DA could be attributed to endogenous factors, such as genetic predisposition or hormone interactions (Auerbach and Ruff 2006), or related to developmental instability. Trinkaus *et al.* (1994) suggest that differences in humeral length and articular dimensions could reflect developmental instability during ontogeny and not mechanical loading, but they do say that this would only be the case if the asymmetry is only above a few percent, with anything greater being a reflection of directional asymmetry.

If these differences were due to developmental instability, the results suggest that it was females who were under a greater amount of stress, especially during ontogeny. Males, on the other hand, were found to be more susceptible to stress over a greater period of time. When significant differences between the fluctuating asymmetry of the sexes were divided into period and settlement type, a similar pattern to DA emerges (see Table 6.5). There were more significant differences between males and females in FA in the Medieval period, while there was a greater difference between the sexes in the urban environment. Similar to the overall patterning of asymmetry differences between the sexes, males and females from the medieval sample differed in 17 measurements (mainly in the upper-limb) and two indices. Males had higher levels of asymmetry in eight measurements and one index, while females were higher in nine measurements and one index. During the Anglo-Saxon period only five measurements significantly differed between the sexes, with females higher in FA in three measurements. The post-medieval sample had seven measurements and two indices that significant differed between males and females. Females were higher in all but one measurement and one index (OCPL, upper limb midshafts). There was a greater difference in fluctuating asymmetry between males and females in urban settlements, with significant differences in 18 measurements and five indices, than in rural settings, which differed in 12 measurements and three indices. Both males and females had an equal number of significant differences in rural settlements. Females from urban settlements were greater in FA in 11 measurements and two indices, while males were greater in seven measurements and three indices.

Table 6.5: Lists of measurements and indices with significant differences in fluctuating asymmetry between males and females grouped by period and settlement type. (M=Males have higher levels of asymmetry, F=Females have higher levels of asymmetry).

Anglo-Saxon	Medieval	Post-Medieval	Rural	Urban
CBAPO M	CNOR M	CBAPO F	CFMTB M	CMPL F
SCL F	CECMIS M	UML F	MRH F	CMPH F
HXMS M	CMPH F	OCPL M	HXMS M	MRH M
OCASH F	MRH M	FIST F	HDT M	HML F
MT2L M	HML F	CZL F	HAPH M	HXMS M
	HXMS M	CZH F	RML F	HIMS M
	HIMS M	Upper long bone lengths F	UML F	HDT M
	HDT M	Upper limb midshafts M	UPL F	HAPH M
	HAPH M		UIMS M	HGT M
	HGT M		OCPL M	RML F
	RML F		OCIS F	UML F
	UML F		CZH F	UPL F
	UPL F		Upper long bone lengths F	SZAW F
	MC3L F		Midshafts M	FIST F
	FIST F		Upper limb midshafts M	TMLP F
	TMLP F			CZL F
	CZH F			CZH F
	Humerus M			MT1L M
	Upper long bone lengths F			Cranium: Temporal F
				Humerus M
				Upper long bone lengths F
				Midshafts M
				Upper limb midshafts M

These results suggest that males were better able to buffer from environmental stress no matter the settling or time period. Males and females were almost equally affected by stress in the Anglo-Saxon and Medieval periods, although females were slightly disadvantaged. During the post-Medieval period in England, females were more adversely affected by the environmental stress brought by the Industrial Revolution (see Section 6.7). As will be discussed in Section 6.6, rural settlements were under more stress than their urban counterparts. The results of sex comparisons indicate that both males and females in the rural settlements reacted similarly to this increased environmental stress, whereas females in the urban environment were at a greater disadvantage than males.

These differences may be explained by social attitudes of the past, as males were more often given preferential treatment during ontogeny and in later life over females. Historical records suggest that parents were more likely to give greater care to male neonates and infants than to females. In many cultures throughout history, males have been known to have had preferential access to food, in both quantity and quality, which increased the risk of malnutrition in females (Ortner 1998). In older children, illnesses affecting boys were reported more frequently in medieval medical records, possibly suggesting that girls were less likely to be taken to see a doctor when ill. Additionally, boys were recorded as being able to recover more quickly from an illness than did girls, which also is suggestive of greater parental investment on behalf of male children (Finucane 2000). Further, osteological stress markers, such as cribra orbitalia and dental enamel hypoplasia, have been found to be more prevalent in females than males during the Medieval period (Roberts and Cox 2003).

The results may suggest that females were less able to buffer against developmental insults or that they were disadvantaged by their social circumstances during ontogeny, which resulted in the accumulation of the higher levels of fluctuating asymmetry seen in the adult skeleton. These findings are contrary to the prevailing hypothesis that males had decreased buffering capabilities in the past (cf. Stinson 1985). Females have been argued to have increased buffing capability linked to a greater immune response to disease caused by differences in physiology between the sexes (e.g. in hormone levels and changes adopted for child bearing) (Ortner 1998). However, the benefits to the immune response in females may be overshadowed by the nutritional stress in the populations in the current study. On the other hand, it is also possible that decreased asymmetry in males can be attributed to a greater number of periods of bilateral cessation of growth, which is caused by a greater susceptibility to developmental stress during ontogeny (Stinson 1985). Therefore, it cannot be ruled out that males have a greater sensitivity to the environment.

In summary, as a result of the analysis, sexual dimorphism in both fluctuating and directional asymmetry was revealed. It is likely that the differences between male and female asymmetry levels are a reflection of skeletal changes brought about by both biomechanical and environmental stress. The results indicate that males were involved in greater upper arm activity, while females repeatedly employed their forearms and hands. At the same time, females were found to be more greatly influenced by environmental stress and/or they could have been less able to buffer from environmental stresses, such as pollution, poor sanitation, overcrowding, poor working and living conditions and malnutrition.

6.5 Asymmetry and Age-at-Death

6.5.1 Directional Asymmetry

6.5.1.1 General Considerations

Adults and subadults were found to have similar median directional asymmetry, although subadults had slightly lower average median levels of DA than adults. Adults were significantly higher in DA than subadults in CVML and MT1L to the left side and SGB, humeral, radial, and ulnar measurements to the right; while subadults were significantly greater in CMAH, FMLP, and CZL to the left side and CMPL, SAL, SZS1, and OCIB to the right. There was a change in directionality between adults and subadults in CFMTN (subadults left), CMAH (subadults left), CECMIS (subadults left), MAL (subadults right), MC2L (subadults left), OCASH (subadults left), MT4L (subadults left), and MT5L (subadults left). Tests for the significance of directionality indicated that, similar to adults (see section 6.2.4), DA was significant in all measurements in the upper limb of subadults, except CVMC, CVLC, SGB, RGH, RMLD, and the metacarpals. Unlike the adults, only seven measurements in the lower limbs, hands, and feet were significantly directional (FML, FIMS, FXST, FIST, FMLP, TINF, and MT3L). This suggests that laterality of the upper limbs is established at an early stage in development and supports the notion that the body appears to exert more energy to maintain symmetry in the lower limb.

Although adults possessed slightly higher levels directional asymmetry than subadults, when these groups were further subdivided into specific age categories, those individuals in late childhood and adolescence had the highest levels of DA. Directional asymmetry was found to increase with age during ontogeny and then peak during adolescence. This increase was followed by a fall in DA in young adulthood and then a gradual increase in asymmetry into mature adulthood (see Figure 6.6). In his review of asymmetry, Hallgrímsson (1998) found that the adolescent growth spurt increased size-related asymmetry. Wilson and Manning (1996) go further to suggest that the increased asymmetry seen in late childhood and adolescence could be a reflection of subadults' accumulation of asymmetry due to the difficulty in maintaining a homeostasis during rapid growth, which is then corrected for before reaching adulthood. This is what is reflected in the results in the current research. As this is a skeletal population, the adolescents in the current study never reached adulthood, these individuals where unable to correct for DA. The increased directionality here may well indicate a greater susceptibility of juvenile bone to biomechanical and/or environmental stress, and thus DA is indirectly measuring developmental instability.

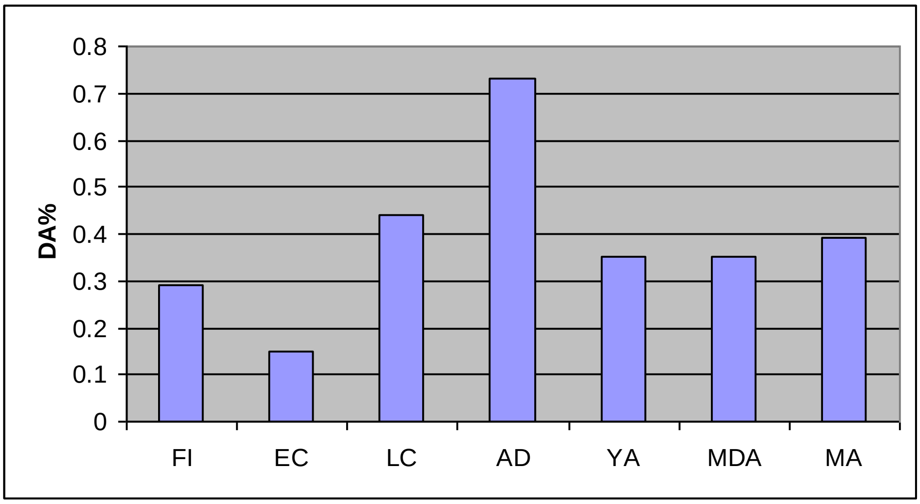

Figure 6.6: Age-related patterning in average median directional asymmetry. (DA%= $\ln(R_j/L_j)$*100).

There were only a few significant differences in DA found between adult sub-groupings and between specific subadult age categories. Only four traits were significantly different after pos-hoc testing of adults, with no overall pattern to the distribution of these differences. Of the 12 traits with significant differences between subadult groups, the majority of differences occurred between adolescent and foetal to infant or early childhood age groups. The adolescent age group had significantly higher levels of directional asymmetry, except in femoral subtrochanteric diameters. Although these significant differences are not informative, a clear pattern emerges when all traits are considered. It is not until the later stages of ontogeny that directionality in human populations becomes established.

6.5.1.2 Length Asymmetry: A Test of the Origins of Asymmetry

To test the possible genetic or biomechanical origins of directional asymmetry, the lengths of the clavicle and long bones are discussed in more detail. As discussed in Chapter 2, there has been much debate about the origin of handedness. If “Annett’s Right Shift Theory” that right handedness is genetically predetermined is correct

(Annett 2002), then it would be expected that this would be reflected in skeletal material from earliest development. Both Schultz (1923) and Stirland (1993a) argue that right-side directionality is established during foetal growth and that it is not influenced by later biomechanical preferences. Schultz (1923; 1926) found that in 52-56% of his sample of foetuses the right humerus was longer. Stirland (1993a, 1993b) also found that during adulthood humeral length asymmetry decreased with age. The current study ascertained that humeral asymmetry is more complicated than previously suggested when all age groups are analysed. Contrary to these earlier studies, humeral length was found to be left-side dominant in the foetal to infancy age group (Figures 6.7). There was then a change in direction to the right, with a steady increase in asymmetry during childhood, which peaked in young adulthood and then fell slightly again to the adolescent levels. The same can be said for actual counts of directionality within the population in humeral length, with 67% of the foetal to infant groups being left-side dominant, while 81% of adolescents were found to be right-sided (Figures 6.8). These findings support Steele and Mays' (1995) study that focused solely on Wharram Percy foetuses and juveniles. They found that of the 14 foetuses, 12 were left-sided and that juveniles were right-sided, but not to the same extent as the adult population. The current study is in agreement with their conclusion that it is the biomechanical environment that affects side dominance and not a genetic predisposition.

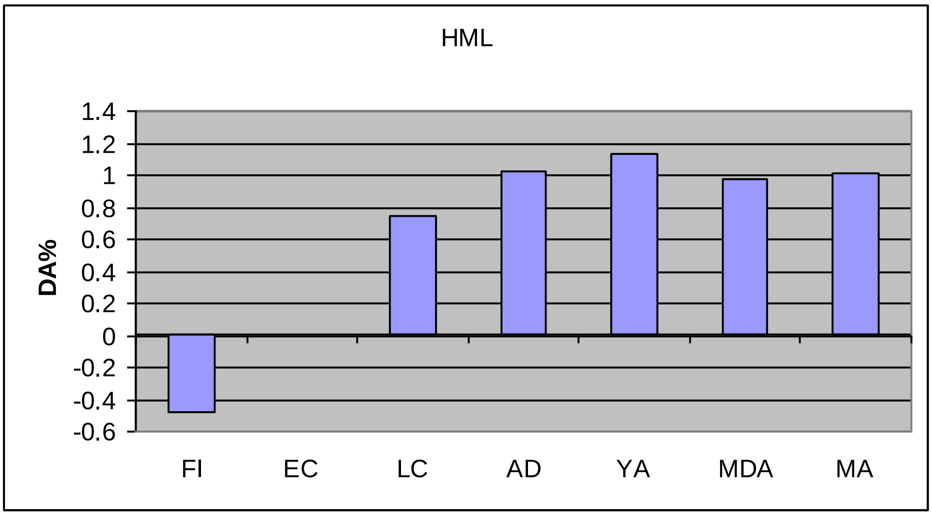

Figure 6.7: Directional asymmetry in humeral maximum length. (DA1=0.00 for the early Childhood group (FI=Foetal to Infant, EC=Early Childhood, LC=Late Childhood, AD=Adolescence, YA=Young Adults, MDA=Middle Adults, and MA=Mature Adults, DA%= $\ln(R_j/L_j)*100$).

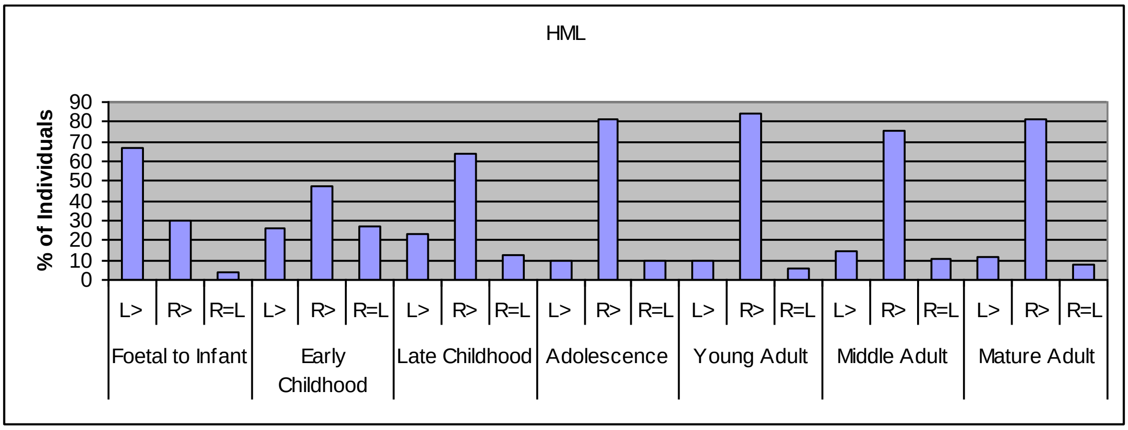

Figure 6.8: Actual counts of directionality in humeral length for individuals from specific age groups expressed as a percentage of the total population.

The argument for the biomechanical origin of handedness is further supported through the other humeral traits and by forearm lengths. Along with maximum length, the humerus also changed direction from left-side dominance in foetal to infancy to right-side dominance by adolescence in its minimum diameter at midshaft and medial lateral measurements of the distal and proximal ends (see Table AP 6.7). Although there was not a change in direction, there was only a slight right-sided population bias for both the ulna and radius in the foetal to infant age group, which became distinctive in later age groups (see Figures 6.9-10). This pattern was similar for radial midshafts. A change in direction from left to right during ontogeny also occurred for RSMLD, UXMS, URN, and UOW (see Table AP 6.7). However, there was clear left-side dominance for all age groups in the clavicle (see Figure 6.11). The only difference in clavicular length dominance occurred with an increase in symmetrical individuals and a reduction in those who were right-sided. This could to some degree be a reflection of underlying asymmetries of the soft tissue of the thorax (*situs solitus*), and therefore not completely a response to biomechanical stimuli.

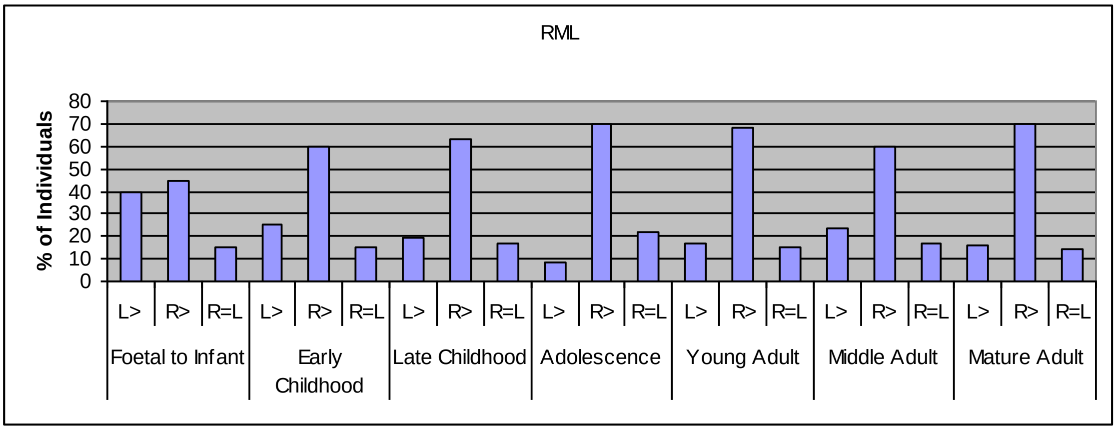

Figure 6.9: Actual counts of directionality in radial length for individuals from specific age groups expressed as a percentage of the total population.

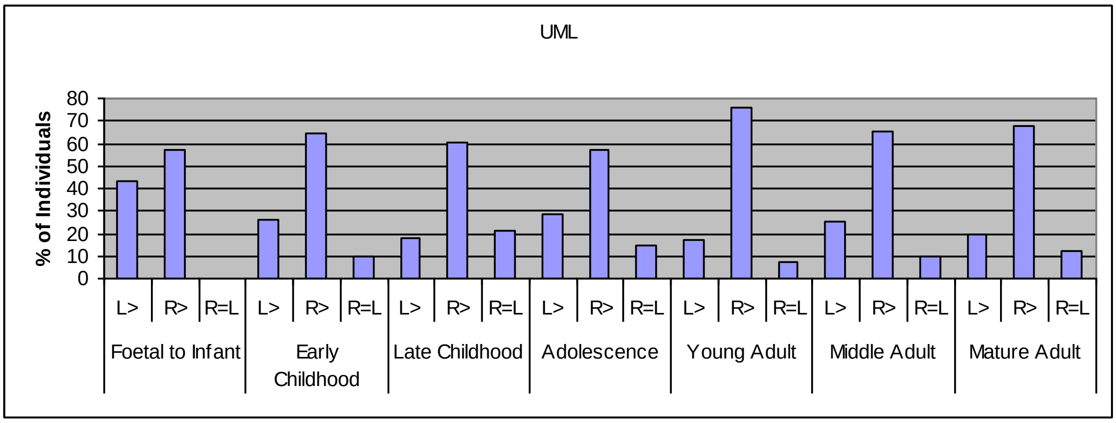

Figure 6.10: Actual counts of directionality in ulnar length for individuals from specific age groups expressed as a percentage of the total population.

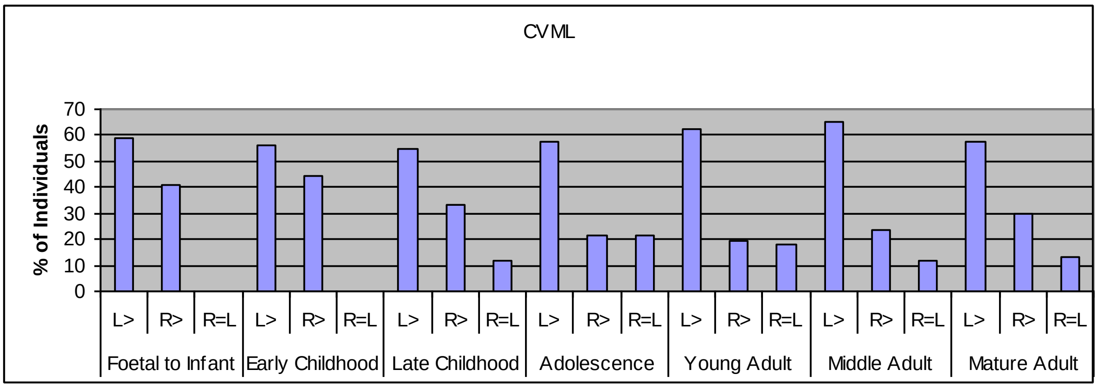

Figure 6.11: Actual counts of directionality in clavicular length for individuals from specific age groups expressed as a percentage of the total population.

The results also imply that there may be a genetic predisposition for symmetry in the lower limbs. There was no distinct side dominance in the actual counts of directionality in the population in femoral and tibial length in the foetal to infant group, while slight left-side dominance remained at similar levels for all age groups (see Figures 6.12-13). This change away from symmetry coincides with the period when an individual adapts a bipedal stance (around one year of age). During this stage of development, the lower limbs are biomechanically altered due to lateralised activity and an asymmetric gait.

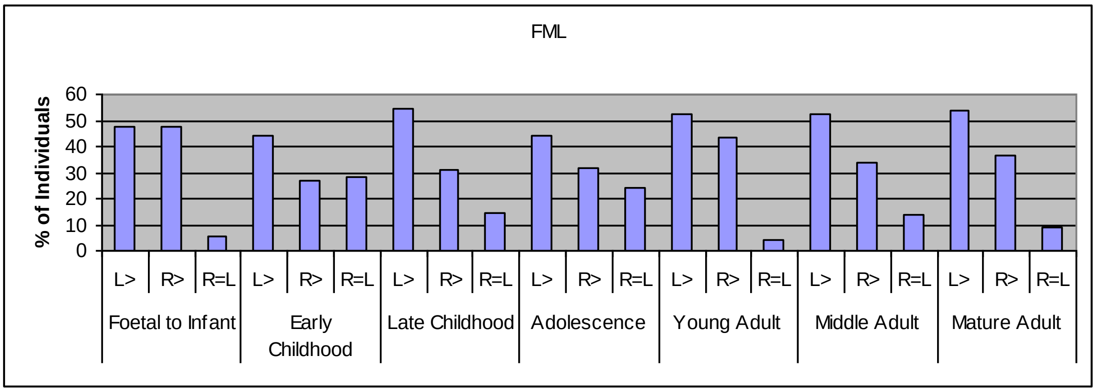

Figure 6.12: Actual counts of directionality in femoral length for individuals from specific age groups expressed as a percentage of the total population.

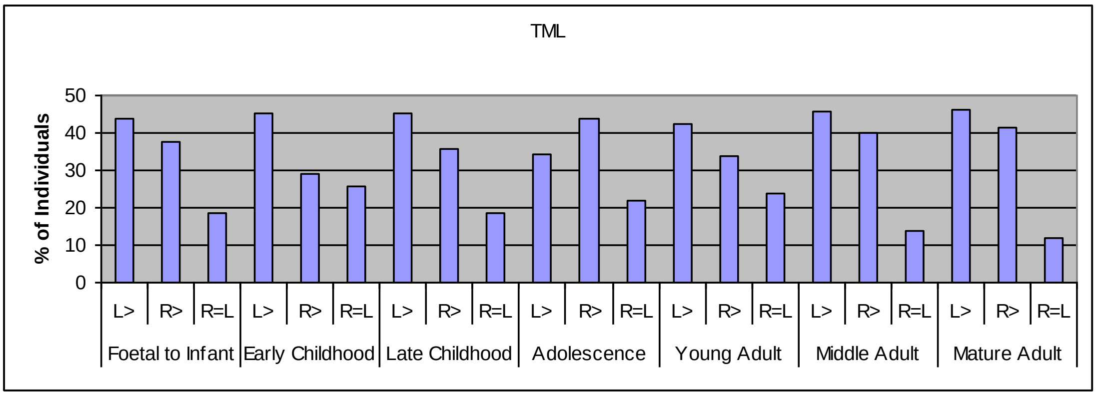

Figure 6.13: Actual counts of directionality in tibial length for individuals from specific age groups expressed as a percentage of the total population.

6.5.2 Fluctuating Asymmetry and Population Outliers

Fluctuating asymmetry was higher in subadults when compared with adults. FA was the highest in the foetal to infancy group, decreasing through childhood, and rising again in adolescence. This was then followed by a fall in FA levels in young adulthood, with a steady rise in FA during adulthood (see Figure 6.14). Subadults also had a significantly higher percentage of outliers than did adults (see Figure 6.15). The foetal to infant group had the greatest percentage of outliers, followed by late childhood and adolescent groups (see Figure 6.16). These results suggest that subadults were either under a greater amount of stress than were adults or that they were more susceptible to such stresses. However, of the traits that were significantly different between the two age groups, adults were found to have twice as many traits where levels of FA were greater than those of subadults. Adults had significantly higher FA in traits of the mandible, clavicle, humerus, radius, sacrum, and lower limbs; while subadults were significantly higher in the scapula, and metacarpals. Adults and subadults both had a number of traits that were significantly higher than the other group in the cranium, ulna, and *os coxae*. This examination would seem to indicate that adults were under greater stress, the opposite of what is implied by average median asymmetry and population outliers.

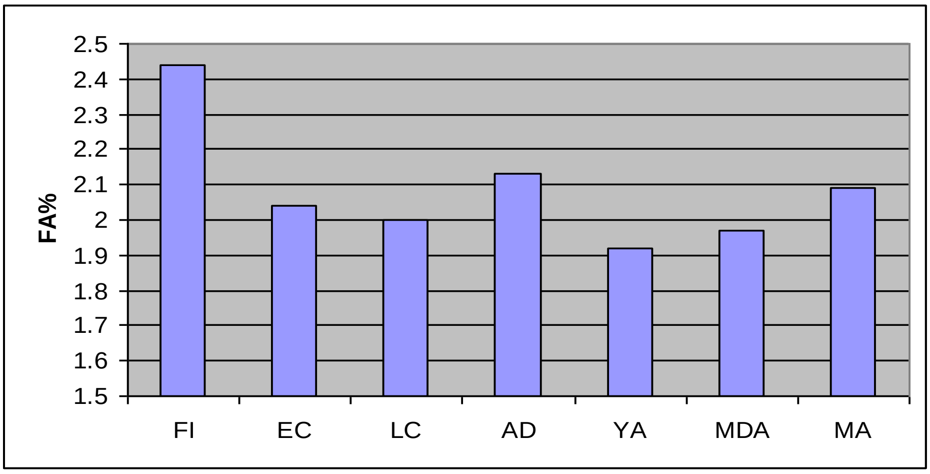

Figure 6.14: Age-related patterning of average median fluctuating asymmetry (FA%=| $\ln(R_j/L_j)$|*100).

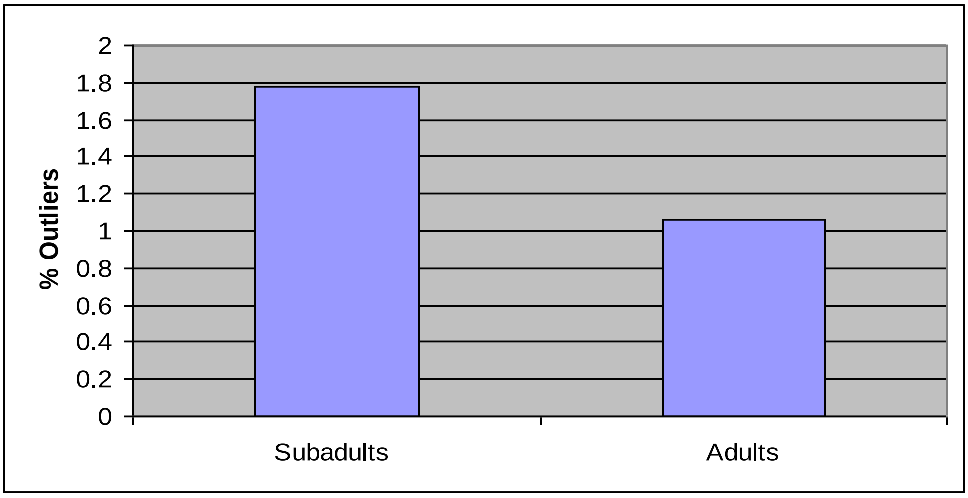

Figure 6.15: Percentage of measurements found to be significant population outliers for subadults and adults.

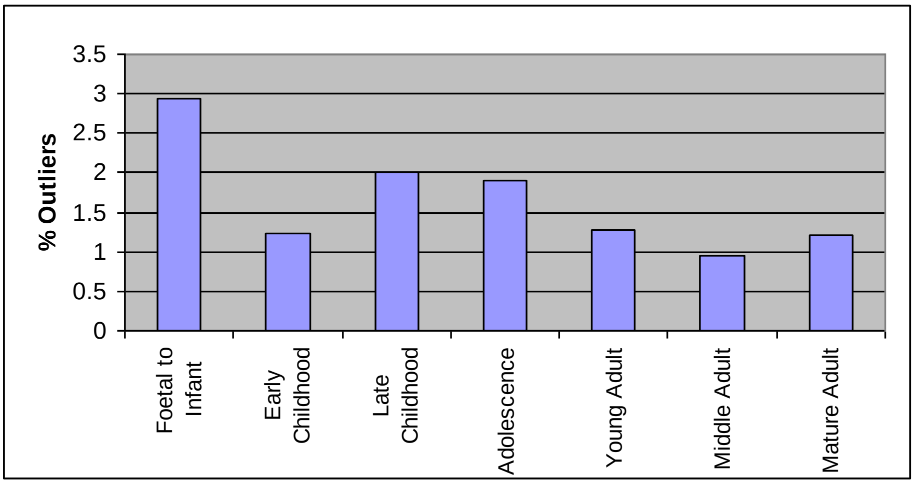

Figure 6.16: Percentage of measurements found to be significant population outliers among specific age groups.

Few significant differences in fluctuating asymmetry between specific adult and subadult age sub-groupings were found. There are only four measurements and two indices that significantly differed within the adult group. The majority of the differences involved mature adults, who had significantly higher FA in UXMS and OCAH and in the mandibular and tarsal index. These significant differences and the average median asymmetry indicate a general increase in asymmetry as age progresses, which support the premise that levels of FA will increase with age (Emlen *et al.* 1993; Palmer *et al.* 1993; Palmer 1994; Møller and Swaddle 1997; Hallgrímsson 1998; Klingenberg 2003).

6.5.3 The Osteological Paradox

In examining the significance of these results, the osteological paradox must also be considered. The osteological paradox states that, in a skeletal population, those individuals with lesions, or in this case asymmetry, may actually be healthier because they lived long enough for them to form and may well have recovered from the period of stress (Wood *et al.* 1992). Although an individual in advanced years who exhibits fluctuating asymmetry has a degree of developmental instability, and therefore suggestive of having lived under stressful conditions, for asymmetry to be detectable in a skeleton an individual has to have had the ability to buffer themselves enough from such disruptions to have been able to survive into adulthood. Those individuals who were not as fortunate to survive a period of acute stress would not necessarily be asymmetric at death. If the subadults represented in the skeletal populations of the current research represent the non-survivors, then by the reasoning of the osteological paradox it could be hypothesised that many of the subadults that did not display asymmetry had died due to some insult during development *before* the appearance and accumulation of asymmetry. If these subadults were able to survive their period of stress, they too would have accumulated asymmetry. Thus if they had survived, both subadults and especially adult levels of fluctuating asymmetry would have been much higher than what has been discovered in the current research.

Similar can be said for the adult sample. Although there are no significant differences between the three adult age groups in the majority of measurements, there is a slight increase in both directional and fluctuating asymmetry with age (which can be interpreted as evidence that asymmetrical changes occur after ontogeny). If the osteological paradox is considered, it could be concluded that there would have been a high probability that the less asymmetric young adults would have had similar asymmetry levels to the mature adults if they had survived the stress that prematurely ended their lives.

6.5.4 Summary

Asymmetry within adult populations was found to increase with age, while subadults had decreasing levels of asymmetry from the prenatal period followed by a rise in late childhood/adolescence. In both adult and subadult groups, the percentage of population outliers was high for the foetal to infant group, declined during childhood, and then rose again in the adolescent group. Directional asymmetry in long bone lengths generally increased with age, although there was a less dramatic increase in directionality in the lower limbs. This suggests that directionality is a behaviourally acquired human trait rather than it being genetically predetermined. This is further evidenced by humeral length, which was the only long bone to change its direction of asymmetry, from left-side dominant in neonates and infants to right-side dominant from early childhood.

To state whether adults or subadults were under greater stress is problematic. A consideration of the osteological paradox is required for all population comparative analysis of subadult populations and, to some extent, with the comparisons made between the differing adult age groups. As cemetery samples represent the non-survivors of a population and as the greatest proportion of asymmetry is acquired during ontogeny, it is reasonable to assume that many of the subadults had not lived long enough for the stressful environment to cause asymmetry to detectable levels. Therefore, direct comparisons between adults and subadult populations may be uninformative and misleading. This osteological conundrum will be considered at greater length in each of the following sections.

6.6 The Urban-Rural Divide: Asymmetry and Urbanisation

6.6.1 Adults

The comparison of adults from urban and rural settlement sites indicated that directional asymmetry, fluctuating asymmetry, and the percentage of outlying measurements were higher in the rural environment (see Figures 6.17-18). When traits were analysed individually, rural populations had 51 measurements with greater DA than did urban centres, which had only 28 (see electronic appendix). Rural settlements had greater DA in the cranium (except for the temporal area), upper limb (but not the clavicle), femur, shoulder, sacro-iliac joint, and knee. They also had the highest directionality in the long bone lengths (barring the tibia) and maximum midshaft diameter measurements (but not in the humerus and tibia). Ten measurements and two indices significantly differed between rural and urban groups, of which there was a change in directionality in two measurements and one index (CFMTNS, SCL, and metatarsals). Rural sites had significantly higher DA in all but SCL, HGT, FLE and metatarsals. These results signify that those individuals living in rural settlements were subjected to slightly greater unilateral biomechanical stress, likely to do with the physical demands involved with agricultural production. It is also suggestive that those individuals buried at the hospital/almshouse would have also been engaged in physically demanding tasks, as the Chichester population had the highest directional symmetry. However, due to the extent of FA, it is possible that these DA results are inflated.

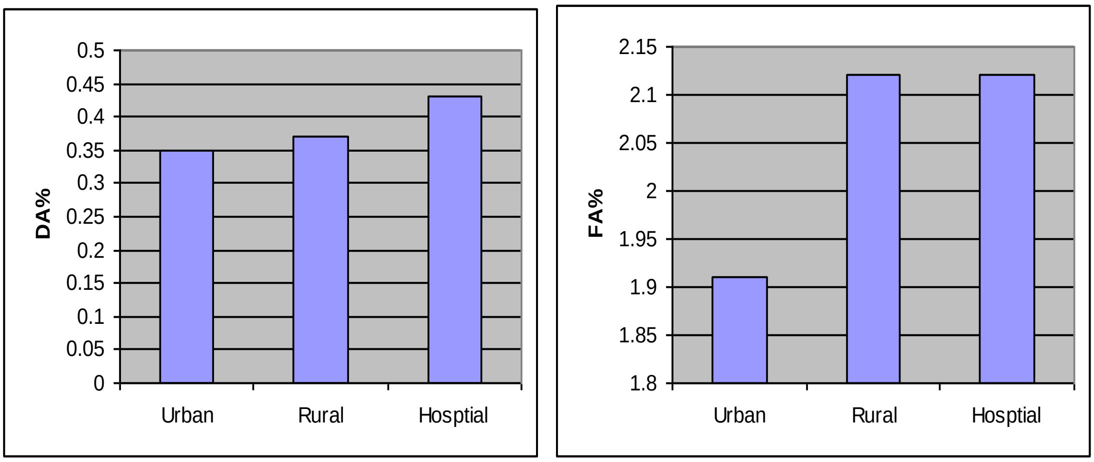

Figure 6.17: Adult directional and fluctuating asymmetry for each settlement type. (DA%= $\ln(R_j/L_j)*100$, FA%=$|\ln(R_j/L_j)|*100$).

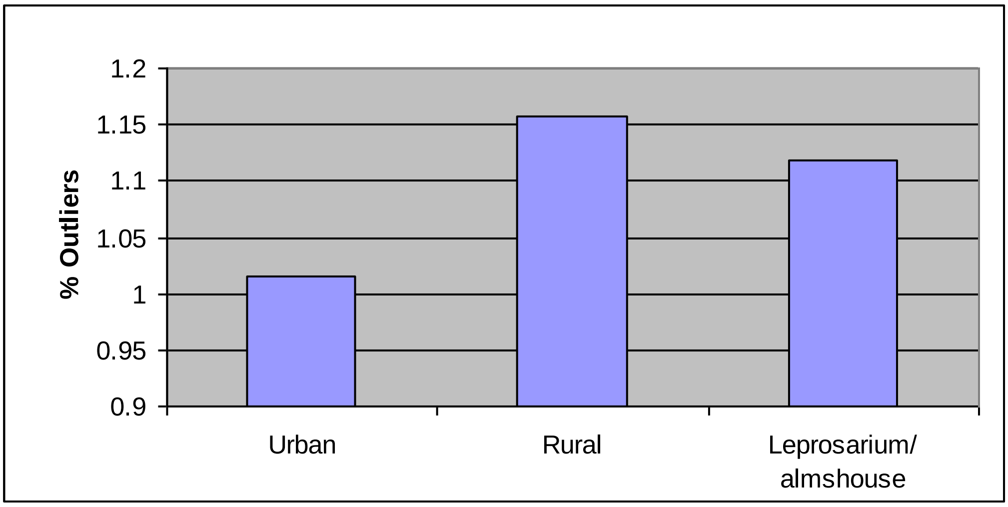

Figure 6.18: Percentage of measurements found to be significant population outliers for adults among settlement types.

There was an even greater urban-rural divide between settlements in fluctuating asymmetry and the percentage of population outliers (see figure 6.17-18 above). Rural sites had comparable levels of average median fluctuating asymmetry and a greater percentage of population outliers than a hospital environment (although not statistically significant). This suggests that developmental instability in rural settlements was greater than that in urban environments, so much so they are comparable to a population that was known to be highly stressed, that of a medieval *leprosarium*/almshouse. Rural settlements had 69 measurements with higher FA than those at urban sites, which had only 28. The only elements in which the urban group dominated in FA were the tarsals (except for length of the calcaneus). Of the 11 measurements and two indices that were found to have significant differences between urban and rural setting, rural sites had higher FA in all but humeral greater tubercle width. Rural sites also had significantly higher FA levels than the *leprosarium*/almshouse in orbital breadth.

These fluctuating asymmetry levels indicate that those living in the rural environment were under greater stress than their urban counterparts. This increased stress can be supported by comparisons of stature, as short stature has also been shown to be a measure of environmental stress (Humphrey 2000; Lewis 2002; Schweich 2005; Mays *et al.* 2008). Wharram Percy individuals, which make up the majority of the rural sample, had the second lowest average stature for males (apart from the rural Chelsea population) and the third shortest stature for females (apart from Blackfriars and St. Helen's) and were generally found to have a lower health status (see Table 3.3).

Although archaeologically and historically it has been demonstrated that urban settlements were crowded, polluted and had poor sanitation, rural environments also were subject to environmental stressors. As has been demonstrated in Chapter 3, rural environments were known to be harsh. From the Anglo-Saxon period to the post-

Medieval period a high proportion of the rural population was known to have had to supplement their incomes through engaging in cheap hired labour in order for their family to be economically sustainable. Rural life became harder during the Medieval period as there was a rise in rents, taxes, and food prices. Famines, food shortages, population migration, and the plagues of the 14th century saw a reduction in the rural population by 40-70%. This reduction in population of the country soon led to an imbalance between supply and demand of resources, leaving rural areas unable to buffer against disasters or further epidemics (Dyer 2003; Schofield and Vince 1994). Conditions worsened during the post-Medieval period as those living in rural areas were often faced with poorer living conditions than individuals living in towns. Government reports on the sanitary conditions of post-medieval England indicate that in many instances the poor in rural areas were worse off than those living in the worst urban slums. During this period agricultural labourers were known to suffer poor nutrition, poor hygiene, overcrowded living conditions, and poor sanitation (Chadwick 1965; McCord 1991).

6.6.2 A Subadult Conundrum

Unlike the adults, subadults from urban settlements had slightly higher average median directional asymmetry than that of rural populations (see figure 6.19). When considered individually, adults from urban centres had greater DA in 44 measurements, while adults from rural were greater in 30. However, significant differences only existed for six measurements and two indices between the settlement types, with rural populations significantly higher in four measurements and one index. Although not significant, urban settlements possessed higher DA in the upper long bone lengths and maximum midshaft diameters (apart from the radial midshaft) and articular dimensions in the hip, elbow, and shoulder. Rural populations had comparably decreased asymmetry in the upper limb, but increased asymmetry in the pelvis and lower limb. These results suggest that, overall, subadults from both populations were highly active; however, although urban populations had increased asymmetry in only a few traits leading them to have a greater average median asymmetry score, analysis of single measurements indicate that urban populations were subject to greater lateralisation through increased biomechanical demands, especially in the upper limb. It is also possible that subadults from urban environments were involved in a greater level of bimanual activity, which led to decreased directional asymmetry in many of their measurements, while creating increased levels in others.

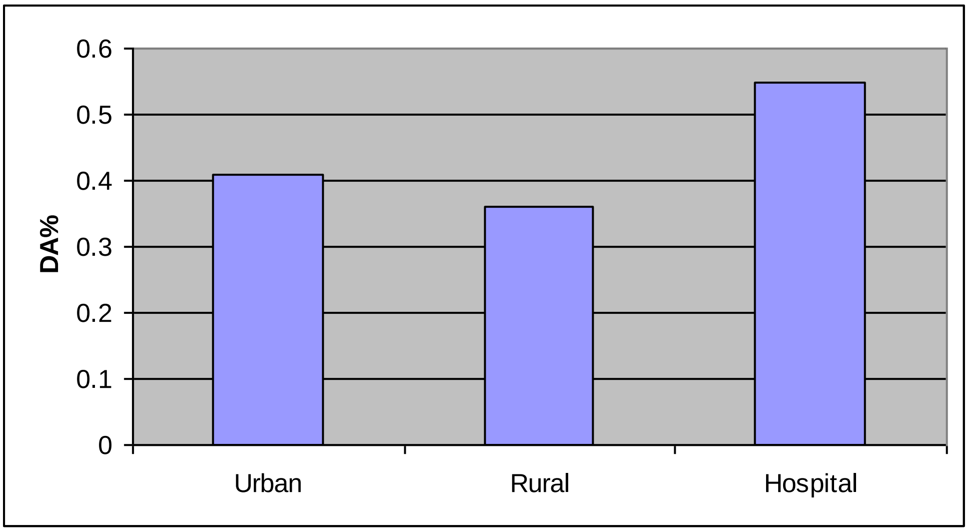

Figure 6.19: Subadult directional asymmetry for each settlement type.
(DA%= $\ln(R_j/L_j)*100$).

Similarly, unlike the adult population, subadults from urban settlements had higher average median fluctuating asymmetry and a greater percentage of population outliers than rural sites (see figure 6.20). There was a significant difference in the percentage of population outliers between rural and urban populations, with the rural sample having proportionally fewer population outliers than the other two settlement types. Fluctuating asymmetry was higher in urban populations in 53 measurements, while rural populations had only 30 measurements with higher FA. Of the ten measurements that significantly differed between urban and rural populations, urban populations had higher levels in all but mastoid process length.

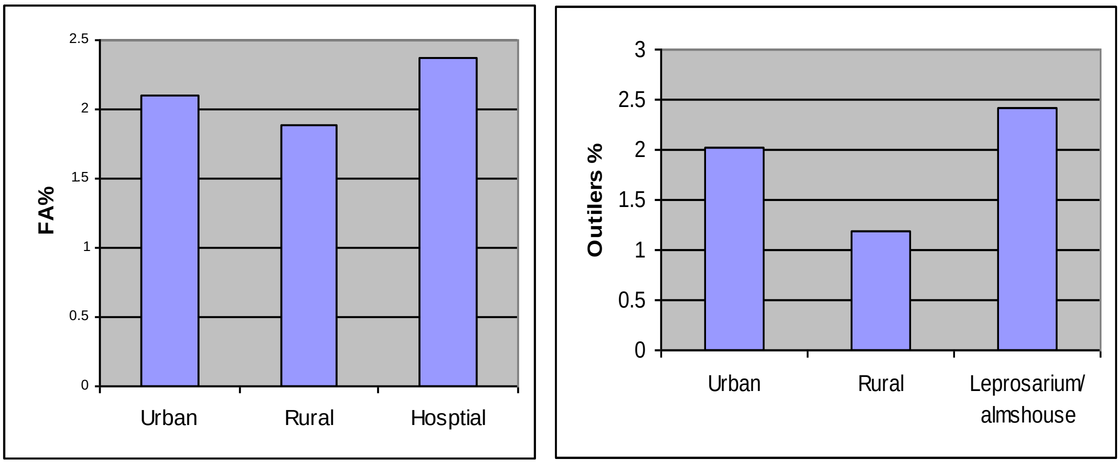

Figure 6.20: Subadult fluctuating asymmetry and population outliers for each settlement type. (FA%=| $\ln(R_j/L_j)$|*100).

If interpretations are made without considering the osteological paradox, these results would seem to suggest that, for subadults, the urban environment was more stressful. They would also support Lewis and Gowland's (2007) study results which found that there was a higher post-neonatal mortality in urban than rural communities indicating environmental stress was greater in urban centres. This would indicate that subadults were less able to buffer from the environmental stresses associated with urban centres than their adult counterparts. However, as has been demonstrated here, the interpretation of asymmetry is not that straightforward. When juvenile mortality rates were compared with asymmetry, it was the rural populations that appeared to exhibit the greater developmental instability. The Wharram Percy sample had the highest percentage of juvenile mortality of all included sites. The population consisted of 47.6% subadults, of which 63.3% did not survive past the age of five (Mays 2007). Many of the subadults from rural environments would have died of an acute developmental instability before asymmetry was acquired. On the other hand, urban juveniles lived during stressful periods for at least long enough for some FA to accumulate. This could suggest that a greater number of subadults from rural environments were succumbing to environmental stress earlier than individuals were in the urban environment.

Subadult settlement comparisons with the Chichester *leprosarium*/ almshouse are even more complicated. Although the population living at the institution was under a great amount of stress, these individuals were being *treated* either for an illness or they were being given at least some relief from their poverty, thus they were living longer than individuals who were similarly afflicted but who were not receiving medical treatment and/or alms and shelter. If the majority of the subadults were, in fact, inmates at SS. James and Mary Magdalene, then it would be reasonable to assume that in this case, subadults would have survived long enough for asymmetry to accumulate.

6.6.3 Summary

There was a definite urban-rural divide in asymmetry between settlements in both subadults and adults. Rural populations had greater developmental instability than urban groups and individuals were apparently less buffered against environmental stresses to which they were known to be subjected throughout history. Stress levels in rural adults were comparable to that of a hospital and almshouse, where it was know that individuals had increased developmental instability. Subadult results were more difficult to interpret due to the fact that these individuals were the non-survivors and therefore may not have accumulated asymmetry from the conditions under which they lived. Although there were higher levels of FA in the subadult urban group, when infant and childhood mortality figures from each site were considered, the rural groups were found to have had suffered greater developmental instability. Those living in rural and urban settlements, however, were both under greater stress as time progressed (see section 6.7).

There was a reduced disparity found between rural and urban groups in directional asymmetry. Both subadult and adult levels of directional asymmetry were similar between urban and rural settlements, although rural populations were slightly higher for adults. Both groups would have been engaged in activities that resulted in increased biomechanical stress. On examination of individual measurements from rural sites, both subadults and adults were higher in directional asymmetry in the lower limb than their counterparts in the urban group. However, adult populations from rural settlements had higher levels DA in the upper limb, while the opposite was true for the subadult populations under study. This indicates differences in activities between the two settlement types, with the rural adults and urban subadults engaged in activities requiring greater lateralisation.

6.7 Diachronic Changes in Asymmetry

6.7.1 Directional Asymmetry

There was a steady rise in the degree of directional asymmetry throughout history. In both subadult and adult populations, Anglo-Saxons had the lowest average median DA, while individuals from the post-Medieval period had noticeably higher DA (see Figures 6.21and 6.22). However, when time period was also broken down by archaeological populations, there were found to be exceptions to this rule (see Figure 6.23 and electronic appendix). (Due to small sample sizes, subadults from multi-period sites will not be discussed here). The highest levels of DA were principally in post-medieval sites, with the exception of Anglo-Saxon Hereford, medieval Hickleton, and medieval Wharram Percy. This suggests that these individuals were engaged in more lateralised activities than the other populations. Although Anglo-Saxon sites predominantly possessed the least amount of DA, post-medieval Wharram Percy, medieval Towton, and medieval Blackfriars also had lower levels of DA. Further, directional asymmetry in medieval Wharram Percy was comparatively higher than the other periods represented at this site. The diachronic changes in directional asymmetry at Wharram Percy from the Medieval to post-Medieval period may be a reflection of the changes in agricultural production and an increase in specialised crafts. By 1517 most of Wharram Percy had been deserted, with land use changing from agriculture to large- scale sheep farming. During the mid-18th century there was known to have been an influx of railway workers at this site (Beresford and Hurst 1976, 1990; Beresford 1979, 1987). Increased lateralisation from the Anglo-Saxon to the post-Medieval periods may be reflective of the general trend of rural populations in England to engage in more specialised crafts to supplement their income, which would therefore cause individuals to be engaged in more activities requiring unilateral movement. On the other hand, the low level of DA in the Towton sample suggests that these individuals were engaged in increased bilateral behaviour when compared with their contemporaries, which could have been due to their military training in weapon use (see Section 6.7). This agrees well with the findings of other researchers (Rhodes and Knüsel 2005; Knüsel 2000a; Stirland 1993a, 1993b).

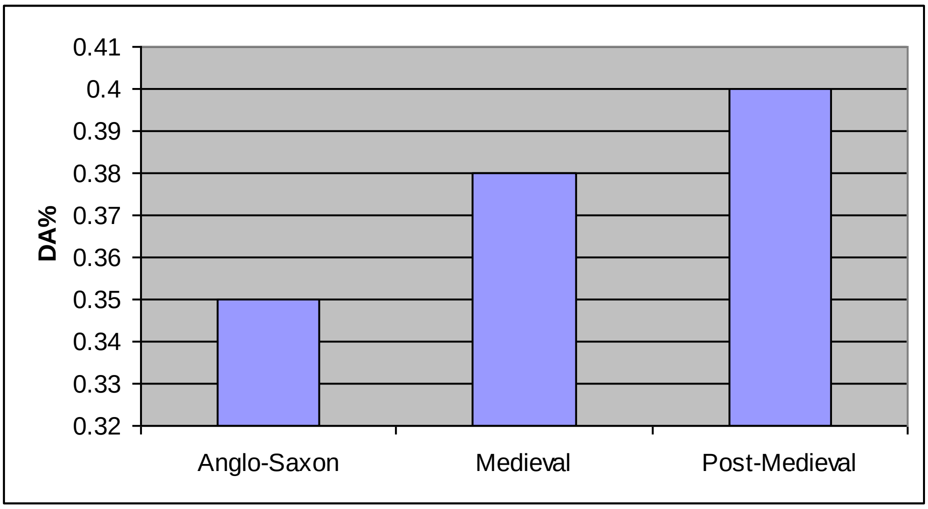

Figure 6.21: Diachronic changes in directional asymmetry in adult populations. (DA%= $\ln(R_j/L_j)*100$).

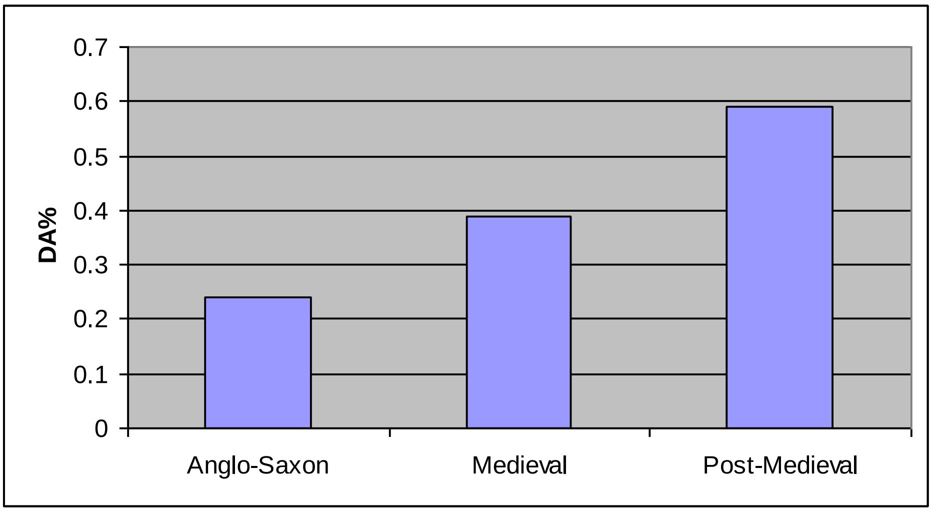

Figure 6.22: Diachronic changes in directional asymmetry in subadult populations. (DA%= $\ln(R_j/L_j)*100$).

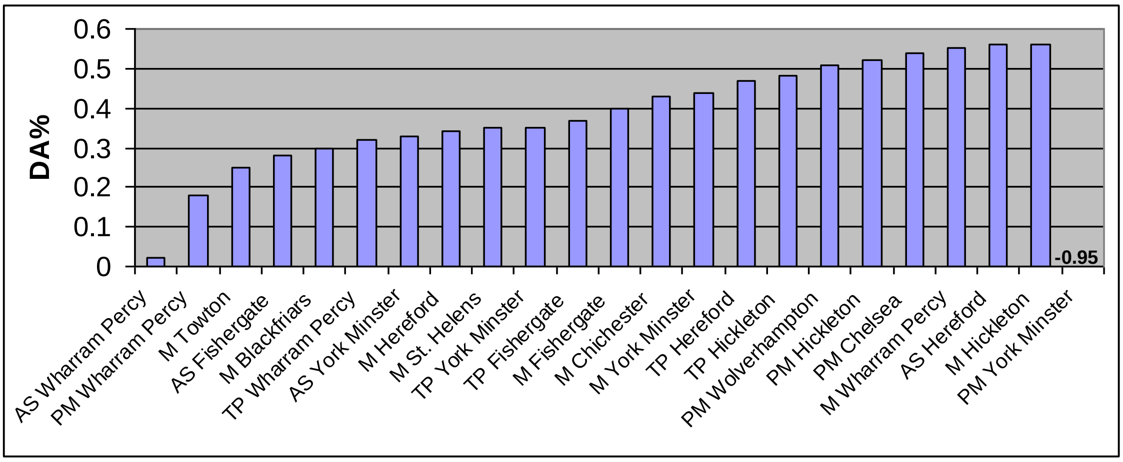

Figure 6.23: Site specific directional asymmetry for adults. (AS=Anglo-Saxon, M=Medieval, PM=Post-Medieval, TP=Total Population, DA%= $\ln(R_j/L_j)*100$).

When measurements were considered separately, Anglo-Saxon and post-medieval adults had an equal number of measurements with higher DA than the other groups. Both Anglo-Saxon and post-medieval adults had 33 measurements higher than the other two populations, while the medieval group only produced 19. Post-medieval individuals possessed predominantly higher DA in the mandible, scapula, and sacrum. Anglo-Saxons had greater levels in humeral and radial lengths and maximum midshaft diameters, indicating an increased lateralised behaviour of the upper limb. The lower limb remained predominantly symmetrical throughout these periods. Post-medieval individuals were more symmetrical when compared with individuals from the other periods in the femoral measurements, except for articular dimensions, which suggest an increased loading of the right hip and knee. All populations exhibited symmetry in the tarsal bones and had low levels of DA in the metatarsals, signifying that symmetry in the foot remained an important factor for weight-bearing and locomotion. Amongst subadults, Anglo-Saxons had the most traits with higher levels of directional asymmetry. Anglo-Saxon subadults had 48 measurements with higher DA than the other two groups, while post-medieval subadults had 34 and the medieval group had only eight. These results imply that medieval individuals were either under lower levels of biomechanical stress, or that they were employed in occupations where mechanical load was almost equal on both sides of the body.

However, of those measurements there were relatively few significant differences found. There were only eight adult measurements and only two subadult measurements that significantly differed between the time periods, all of which occurred in the upper body. There were also few significant differences when diachronic changes were compared for adult multi-period sites (see electronic appendix). The most significant differences existed between Anglo-Saxon and medieval Fishergate individuals, in seven measurements (CMAH, CMPH, COPO, HGT, OCH, URN, and UOW). The site with the least significant differences between periods was Hereford, with medieval individuals and Anglo-Saxons only differing in two measurements (FML and FIST). This indicates that although there was a slight diachronic rise in DA, directional asymmetry at specific sites remained relatively similar throughout the periods.

6.7.2 Fluctuating Asymmetry and Population Outliers

The results demonstrate a clear diachronic rise in population outlying measurements and fluctuating asymmetry. Significant differences were found in population outliers amongst the periods, with post-medieval individuals having proportionately over twice as many population outliers as among Anglo-Saxons in the adult group and three times that of both medieval and Anglo-Saxon subadults (see Figures 6.24-25). Anglo-Saxon subadults had the second highest average median FA, after the post-medieval sample (see Figure 6.26). As with directional asymmetry, average median adult FA steadily rose from the Anglo-Saxon to the post-Medieval periods (see Figure 6.27).

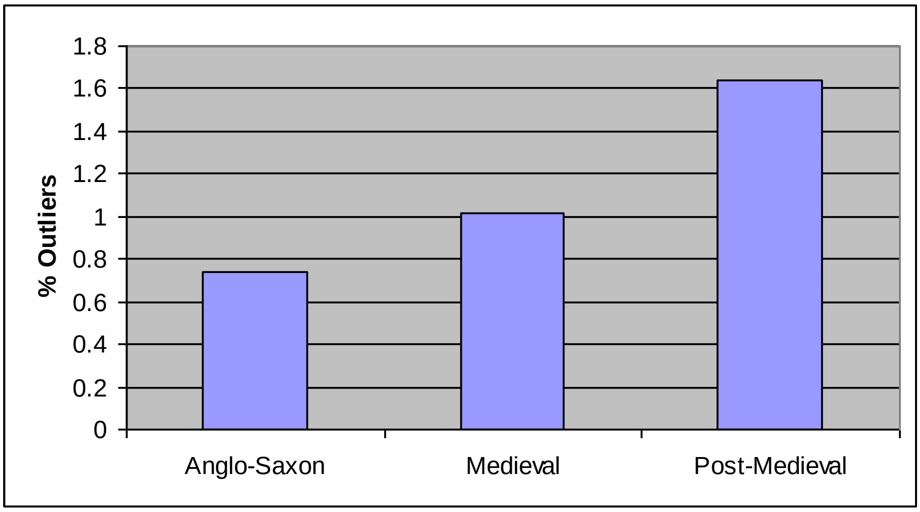

Figure 6.24: Diachronic changes in the percentage of measurements found to be significant population outliers for adults.

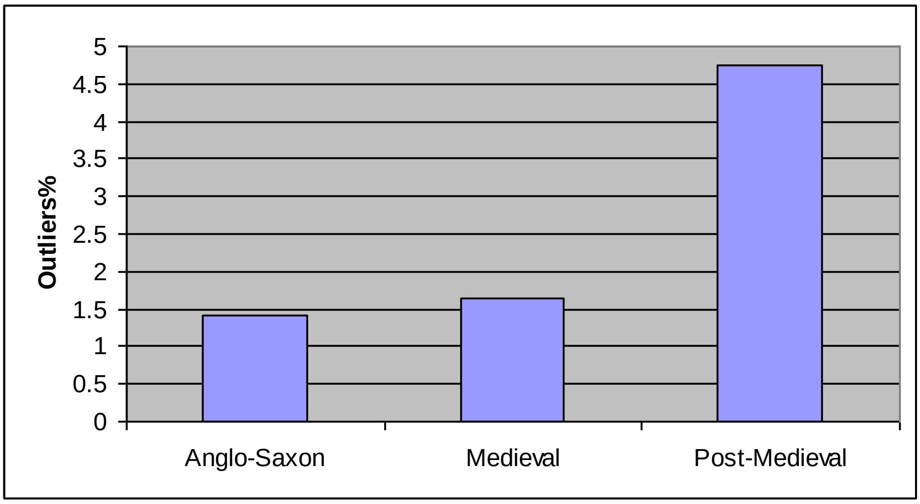

Figure 6.25: Diachronic changes in the percentage of measurements found to be significant population outliers for subadults.

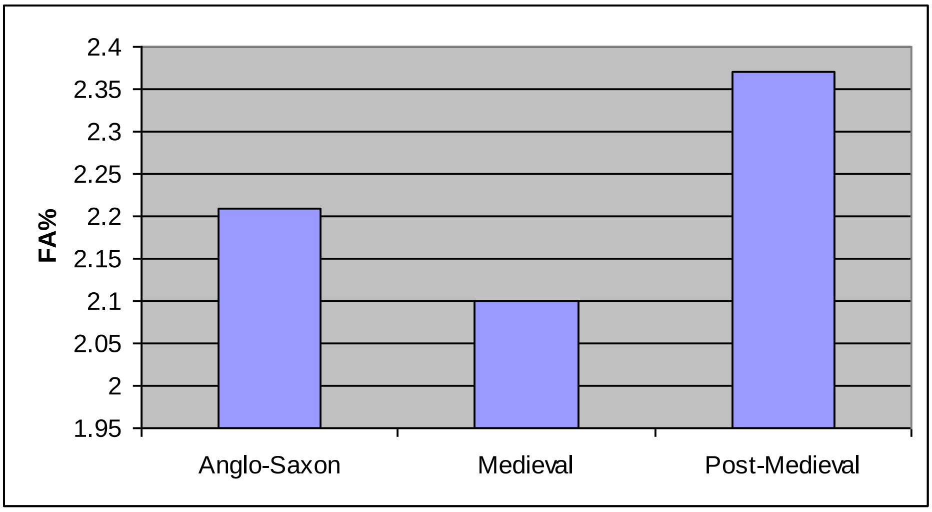

Figure 6.26: Diachronic changes in fluctuating asymmetry in subadult populations. (FA%=| $\ln(R_j/L_j)$|*100).

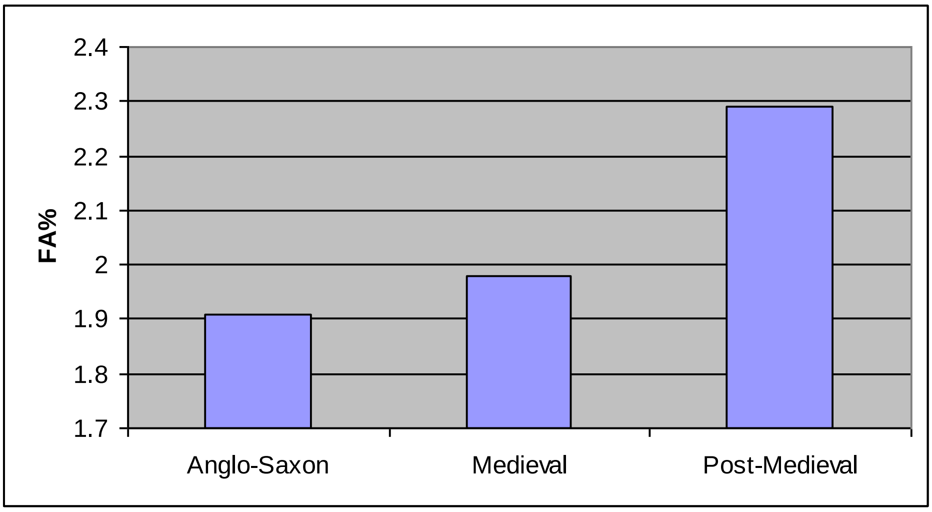

Figure 6.27: Diachronic changes in fluctuating asymmetry in adult populations. (FA%=| $\ln(R_j/L_j)$|*100).

When measurements were considered individually, fluctuating asymmetry was clearly more prominent in the post-medieval sample (see electronic appendix). The post-medieval population had higher FA in 67 adult measurements and 27 indices when compared to the other time periods. Anglo-Saxons had 20 measurements and one index higher than the other time periods, while the medieval group had only 10 measurements and four indices that were higher. Similarly, post-medieval subadults had the most measurements that were higher than those of the other groups, with 36 measurements and 10 indices being higher. Unlike the adult group, Anglo-Saxon subadults had a greater number of measurements that were higher than those of sub-adults from medieval burials; Anglo-Saxons were higher in 28 measurement and nine indices being higher, while medieval subadults were higher in 23 measurements and four indices.

In the adult sample there were a considerable number of significant differences between time periods, while this was not the case with subadults. Significant differences existed between periods in 27 of the measurements and 16 indices in the adult populations. All of these significant differences were from post-medieval sites, which had the highest levels of FA, except for CNMS where the Medieval period had the highest levels and for HML and MT4L where the Anglo-Saxon sample was higher. These differences included the majority of cranial measurements and an almost equal number of traits in the upper and lower limbs. This is not like DA where all significant differences in measurements were solely in the upper limb (barring the indices). Subadult periods, on the other hand, significantly differed in only five measurements and one index, with the post-Medieval period having the greater extent of FA for these measurements.

When adult sites were separated by time period, little differences in average median FA existed between the samples, except between the individual post-medieval sites (subadult sample sizes were too small to make comparisons). The archaeological sites possessing the highest median FA for adults were from the post-medieval period, save for medieval Hickleton, which had the highest levels of FA (see Figure 6.). Although the post-medieval Hickleton sample had comparatively higher average median FA than all other sites, it possessed lower levels than the medieval Hickleton individuals, suggesting that these medieval individuals were under greater stress than the post-medieval site. Of the post-medieval sites, York Minster had the highest FA. However, post-medieval York Minster consisted of a small sample size of less than five individuals, thus limiting interpretation and statistical testing. Post-medieval Wharram Percy's average median FA was higher than that of the Chelsea sample, but lower than the Wolverhampton sample. This ranking is consistent with the socio-economic status of the post-medieval groups: Wolverhampton epitomises the low status urban industrial population, Wharram Percy that of a rural populations, and Chelsea that of higher status populations (see section 6.8.3 for a more complete discussion). Of those sites with multiple periods, the results indicate that FA remained constant throughout history. Wharram Percy post-medieval individuals possessed higher average median fluctuating asymmetry (at 2.3%) than the medieval sample from that site (at 2.1%) (Figure 6.28 and electronic appendix). However, only one measurement significantly differed in fluctuating asymmetry between post-Medieval and earlier periods, OCAH ($z=2.697$, $p=0.02$) (see electronic appendix). Similarly, between-period comparisons of the Hickleton population indicated only five measurements that significantly differed (see electronic appendix).

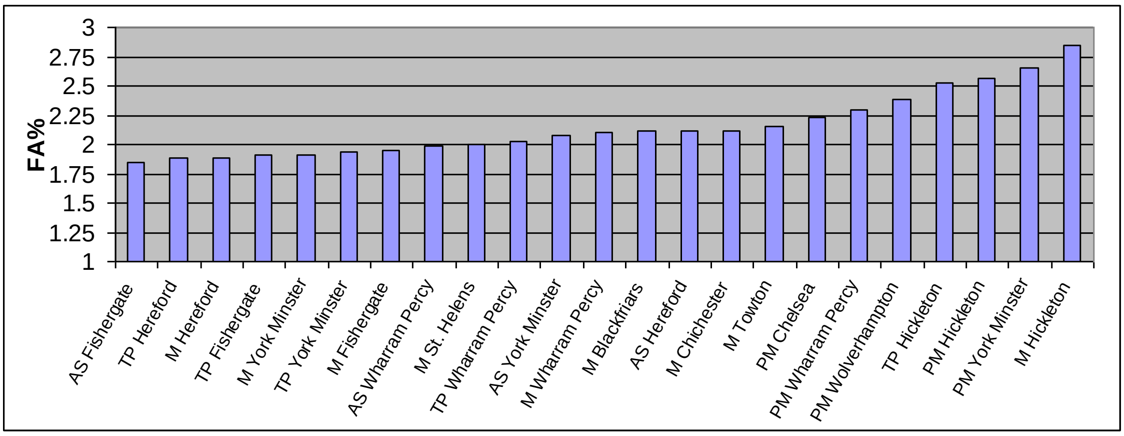

Figure 6.28: Site specific fluctuating asymmetry for adults. (AS=Anglo-Saxon, M=Medieval, PM=Post-Medieval, TP=Total Population, FA%=| $\ln(R_j/L_j)$|*100).

Although there was historical and archaeological evidence of environmental stress during the Anglo-Saxon and Medieval periods, environmental stress in England had increased dramatically by the height of the Industrial Revolution (see Chapter 3 for a full discussion of living conditions during these periods). One of the main causes of environmental stress was the population explosion in the post-Medieval period. From 1066 to 1650 there was a population increase of only 2.5 million; however, in less than one generation, from 1800-1851, there was a population increase of 18.4 million people. Not only was there an increase in population, but there was also a redistribution of this population. At the end of the Anglo-Saxon period 80% of the population was still living in rural areas, while two thirds of the population lived in urban centres by 1881 (Hill 1969; McCord 1991; Outhwaite 1991; Schofield and Vince 1994; Prest 1998; Roberts and Cox 2003; Dryer 2003). This population expansion and relocation did not only cause overcrowded conditions, but it had left the English people ill prepared for the consequences of such a density. As discussed in Chapter 3, both urban and rural areas were disadvantaged by the changes due to industrialisation. In much of England, sanitary conditions were reported to be intolerable (see Chadwick 1965). There was a widening social divide between the rich and the poor, which had never been seen before. From the 18th to the middle of the 19th century between one in five and one in 15 people were receiving poor relief. Further, the health of the population was diminished, as epidemics were rife and the majority of the population suffered malnutrition (Hill 1969; McCord 1991; Outhwaite 1991; Prest 1998). Even those individuals of higher status would have been affected. Adult and child mortality figures for the post-Medieval period indicate that they were high for both the poor and the wealthy alike (Hill 1969; Razzell and Spence 2006).

It has been previously demonstrated that the higher levels of developmental instability are in direct proportion to environmental, health, and social stresses (McManus 1982, Palmer 1994, Fields *et al.* 1995, and Møller and Swaddle 2002). In her study of child and infant mortality and morbidity in medieval to post-medieval England, Lewis (2000) concluded that differences in childhood health were more to do with industrialisation than urbanisation. Similar to the results of the current research, she found that although the post-medieval Christ Church Spitalfields population was of middle to upper class origin, there was a greater delay in growth than found in the lower class medieval St. Helen's sample. She concludes that the socio-economic "status did not buffer children from the detrimental effects of the industrial environment" (Lewis 2000: 57). In a follow up study, Lewis and Gowland (2007) found that environmental stress had a greater influence on infant mortality rates in the post-Medieval period than in the Anglo-Saxon and Medieval periods in England. Similar results were found in Central Europe by Kujanová *et al.* (2008), where levels of DA and FA were reduced in the medieval sample when compared with a 1930s sample. They found that the modern sample had 70% more asymmetry than the medieval sample, leading the researchers to conclude there was increased environmental stress in recent populations. Gawlikowska *et al.* (2007) found significant difference in FA between crania of a modern and archaeological population from Poland, with asymmetry higher in the stressed modern population. The results of the current research indicate that there was a diachronic increase in developmental instability that can be linked to the industrialisation of England.

6.7.3 The Osteological Paradox Revisited

Unlike the comparisons between settlement types, when juvenile mortality in the post-Medieval period was also considered, levels of asymmetry coincided with mortality rates in the site samples under study. Although the results indicate that there were few significant differences in subadult FA levels between the time periods, there was still a substantial rise in average median fluctuating asymmetry and a significant increase in the percentage of population outliers. Unlike urban-rural comparisons, the absence of FA in this case does not suggest higher stress. In fact, subadults from the post-Medieval period, having the greatest amount of fluctuating asymmetry, would have been under even greater stress than the results suggest. If juvenile mortality figures from the Industrial Revolution are taken into consideration, children during this period had a reduced chance of survival into adulthood than their medieval counterparts. Child mortality was twenty times what it is today, as one in four died before they attained 10 years of age and one in six did so before they completed their first year of life (Prest 1998; Adams and Driver 2007). Although medieval mortality figures are problematic, such studies as Lewis' (2002), have found that infant and child mortality was greater in post-medieval populations than in medieval ones. It is possible (according to the osteological paradox) that post-medieval children were not surviving long enough for asymmetries to accumulate in the skeleton because the environmental stress (be it pathological load, pollution, nutrition, work load, overcrowding, etc) was too great. However, unlike comparisons of subadult FA between rural and urban groups, post-medieval sites were not only found to have a greater level of FA, but they were also had the highest child mortality. It is postulated that if all children had survived, there would have been higher population asymmetry levels and a greater percentage of outliers in the post-medieval sample.

6.7.4 Summary

The results provided evidence for a definite diachronic increase in asymmetry. Although there were few significant differences in measurements between the three time periods in DA, there was a general pattern of an increase in laterality, which is suggested to reflect changes in biomechanical behaviour in response to the industrialization of England. As a result of the Industrial Revolution, there was a well documented increase in environmental stress. Based on the higher fluctuating asymmetry scores and population outliers, it is concluded that post-medieval populations had greater developmental instability, which was caused by an increase in population density, urban and rural poverty, pathogen load, environmental pollution (especially air pollution), and poor sanitation not seen to the same extent in other time periods. As fluctuating asymmetry was found to be so significant, it is suggested that directional asymmetry results may be inflated. The differences in asymmetry between the three time periods were indeed caused by environmental stress and were not solely due to biomechanical differences. As post-medieval period was found to have the highest levels of asymmetry and they have been found by other researchers to have further skeletal stress markers that indicate these populations were under a great amount of stress, we may need to rethink our use of these populations of establishing osteological methods (such as sexing and age estimation based on metrical analysis) as, unlike other populations, the development of their skeletons have been altered in response to environmental stress.

6.8 Revealing Socio-Economic Status through Asymmetry: Inter-Site Comparisons

6.8.1 Directional Asymmetry

Twenty-five adult measurements differed in directional asymmetry between the sample populations, while only 15 subadult measurements differed. These differences were evenly distributed throughout the skeleton, with the only emphasis being on the pectoral girdle and humerus in the adult samples. As the distribution of between site differences lacked a specific pattern, specific inferences could not be made about variations in specific activities. However, there are two sites that do have asymmetries that have obvious differences from the other populations. Wolverhampton was significantly higher than seven of the sites in adult humeral midshaft diameter, four of the sites in humeral shaft diameter at the deltoid tuberosity, and two sites in the dimensions of the humeral greater tubercle. This suggests that these individuals were engaged in repetitive unilateral activity involving the arm to a greater degree that those from other sites. Blackfriars was significantly higher in mastoid process length than five of the adult populations and two of the subadult ones, which may suggest a higher frequency of torticollis within this site (although this would need to be confirmed with other measurements and a visual inspection of the material).

Of the 11 archaeological sites, inter-site comparisons of average median directional asymmetry indicate that subadults from Blackfriars, Chichester, Fishergate, Wharram Percy and York Minster were higher in DA than their adult counterparts. Adults had higher DA than subadults from Hereford, Hickleton, St. Helen’s and Wolverhampton

(Figures 6.29-30). The highest levels of average median directional asymmetry in the adult sample were determined to be that from Chelsea, Wolverhampton and Hickleton. Chelsea possessed the highest median directional asymmetry in indices for the temporal area of the cranium, scapula, femur, tibia, and lower limbs. Wolverhampton had the highest levels of DA in the cranial vault, ulna, metacarpals, *os coxae*, upper limb and lengths; and Hickleton in the orbit, viscerocranium, cranial base, mandible, humerus, radius, tibia, metatarsals, and upper limb as a whole. As it was found that when compared with the rest of the populations these three post-medieval sites also had significantly higher FA in many of the measurements and indices, it is possible that these DA scores have been inflated by the effects of environmental stress. Ranking of average median levels of subadult DA based on site was almost the reverse of that produced by the adults, except at St. Helen's and Wharram Percy. Subadult populations of Blackfriars, York Minster, and Fishergate were found to have the highest DA, while Hickleton, St. Helen's and Wolverhampton had the lowest.

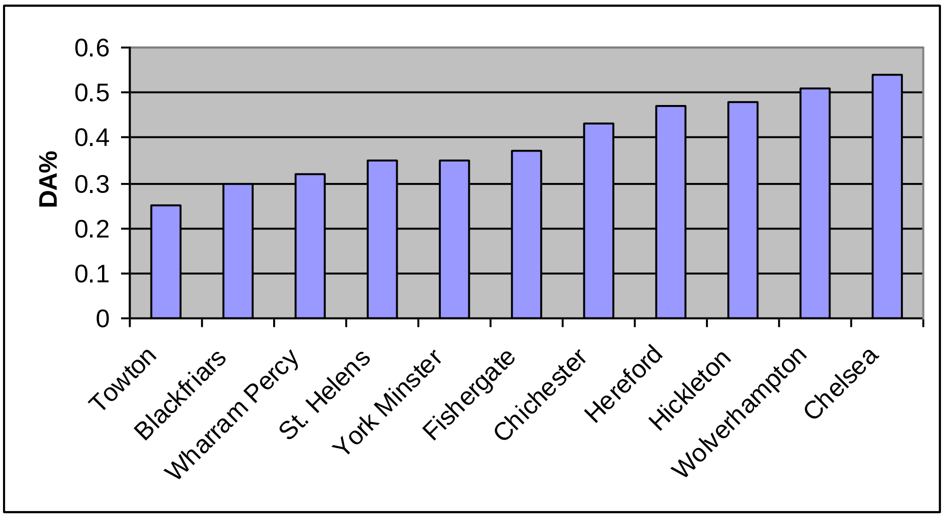

Figure 6.29: Adult inter-site comparisons of directional asymmetry.
(DA%= $\ln(R_j/L_j)*100$).

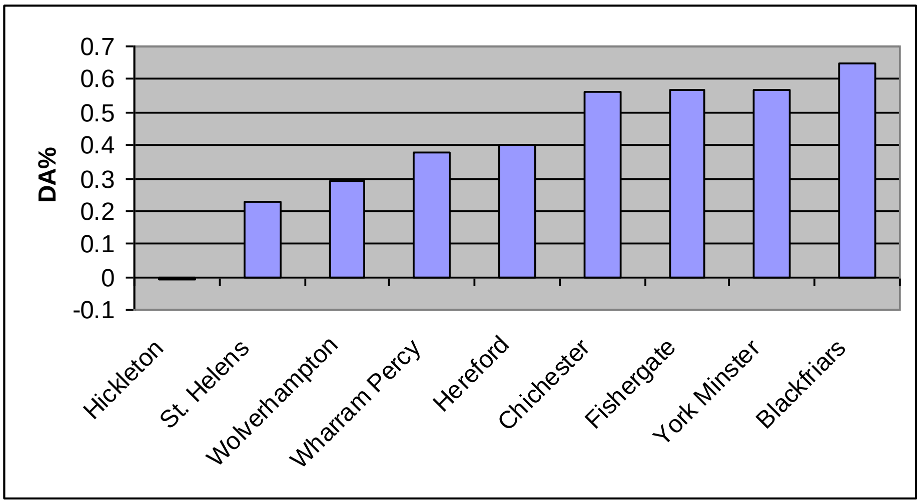

Figure 6.30: Subadult inter-site comparisons of directional asymmetry. (DA%= $\ln(R_j/L_j)*100$).

6.8.2 Fluctuating Asymmetry and Population Outliers

There was little variation in average median fluctuating asymmetry between sites, with average medians falling between 1.89 to 2.53% for adults and 1.89 to 2.93% for subadults. However, subadults from specific sites were consistently higher in FA and population outliers than their adult counterparts (Figures 6.31-34). For subadults, Wolverhampton, Hickleton, and Chichester had the highest average median FA; while Wharram Percy, Hereford, and St. Helen's had the lowest. Similarly, Wolverhampton, Chelsea and Hickleton were found to have the greatest percentage of outliers; whereas York Minster, St. Helen's and Blackfriars demonstrated the lowest. Adults from Hereford, and Fishergate, and York Minster had the lowest average median asymmetry, while, as with directional asymmetry, Hickleton, Wolverhampton, and Chelsea were found to have the highest median FA. Of these sites, Hickleton possessed the highest average adult median FA in indices of the viscerocranium, temporal area of the cranium, cranial vault, ulna, tarsals and lower limb; Wolverhampton for clavicle, humerus, pelvis, sacrum, tibia, metatarsals, upper and lower long bone lengths, upper limb midshaft diameters, the hip, and the knee; and Chelsea in the scapula, upper limb, lower limb midshaft diameters, and shoulder. The highest percentage of outliers among adults from these sites came from Wolverhampton, Hickleton and St. Helen's and the lowest percentage from Hereford, Blackfriars, and York Minster. These results suggest that of the archaeological sites, Wolverhampton, Hickleton, Chelsea and Chichester were under higher levels of environmental stress. As has been demonstrated in section 6.7, sites from the post-Medieval period were found to have greater developmental instability than those sites from previous periods.

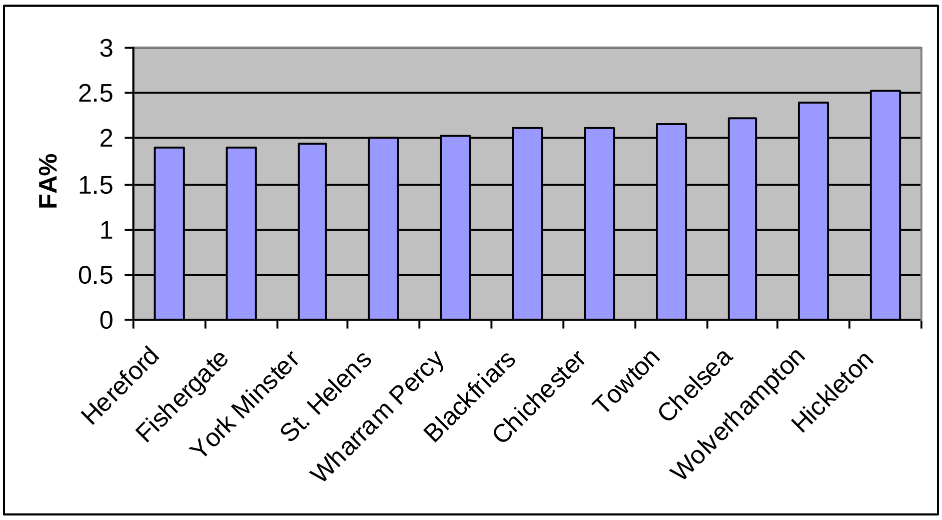

Figure 6.31: Adult inter-site comparisons of fluctuating asymmetry. (FA%=| $\ln(R_j/L_j)$|*100).

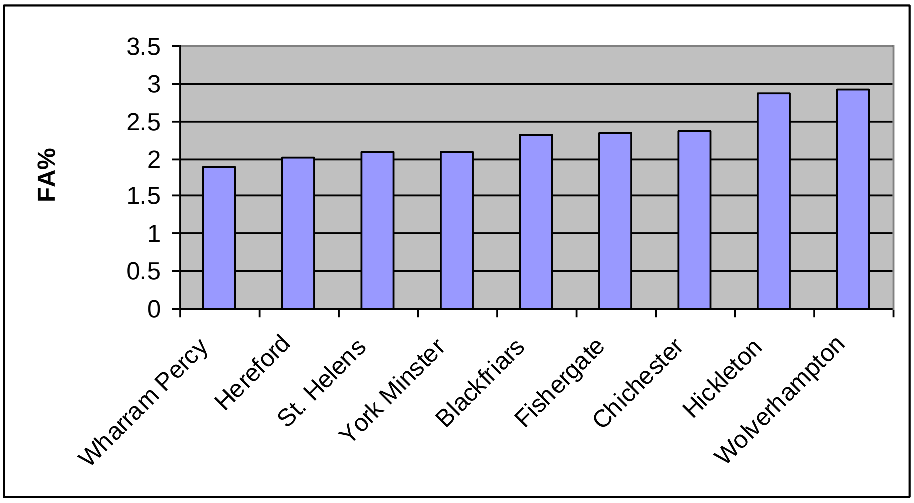

Figure 6.32: Subadult inter-site comparisons of fluctuating asymmetry. (FA%=| $\ln(R_j/L_j)$|*100).

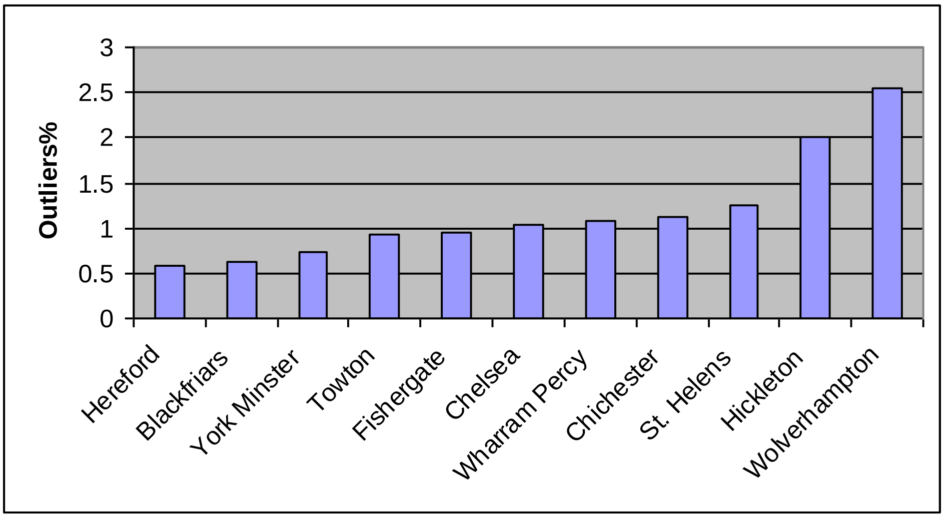

Figure 6.33: Percentage of adult outlying measurements for each archaeological site.

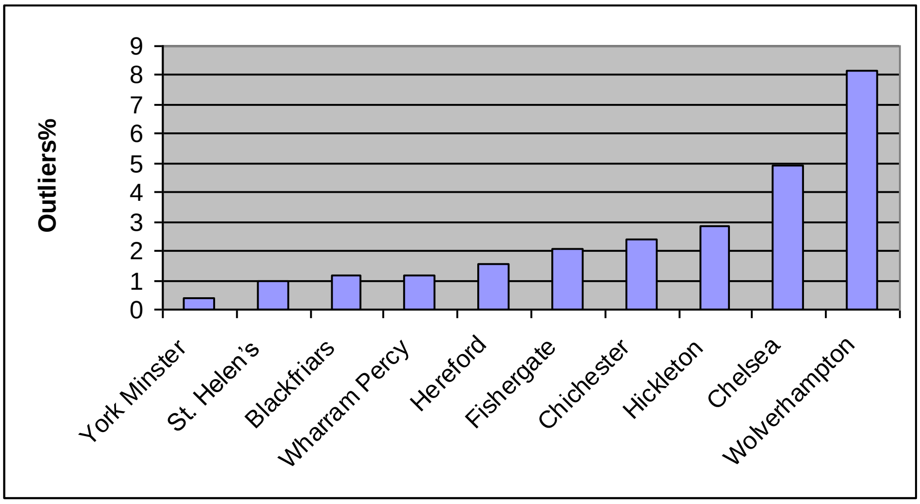

Figure 6.34: Percentage of subadult outlying measurements for each archaeological site.

Significant differences existed in 33 measurements and nine indices between the adult samples, and 14 measurements and five indices between the subadult populations, indicating a high degree of variability in fluctuating asymmetry and, thus, levels of environmental stress between archaeological sites. Although subadults had fewer traits with significant differences in FA between the sites than found among adults, as discussed earlier, this could be evidence of the osteological paradox at work, with many individuals dying before the accumulation of FA had become significant. Unlike directional asymmetry, patterns emerged in those measurements that significantly differed. Adults from York Minster had significantly lower asymmetry than the samples from other sites in cranial measurements. Chichester adults were significantly higher in cranial, femoral and talar measurements. Wharram Percy adults were significantly higher for humeral shaft measurements, while subadults from this site were consistently lower in FA levels (except for CMPL and the temporal region of the cranium). As so many significant differences existed between populations in specific measurements of fluctuating asymmetry, it can be inferred that this heightened asymmetry could be related to socio-economic and environmental differences. Møller and Swaddle (1997: 150) state that "if it is assumed that genetic diversity is not great between populations of the same species…then any differences in fluctuating asymmetry between populations are most likely due to relative differences in environmental conditions."

6.8.3 Socio-economic status

One of the ways in which to assess socio-economic status from skeletal remains is to analyse between population differences in asymmetry. It is hypothesised that those samples that were of low social and economic status would also have had increased DA, FA, and percentage of population outliers. Individuals from the lower levels of society would have been employed in occupations that would require repetitive strenuous activities, which may be reflected in heightened levels of DA. These lower status individuals would also have increased FA and greater percentage of outliers. Developmental instability in this case would have been caused by access to limited resources, which would have in turn caused poor nutrition, increased physical demand, limited access to health care, and an increase in pathogen load. They would have been living in areas with poor quality housing and water, poor sanitation, environmental pollution, and overcrowding. Higher status individuals on the other hand would have been partially shielded from many of these insults due to their privileged lifestyle. The populations included in this study assessed as of low socio-economic status through an examination of the historical and archaeological record are St. Helen's, Wharram Percy, Chichester and Wolverhampton, while high status can be attributed to the Chelsea, York Minster and Anglo-Saxon Hereford sites, while the remaining five sample populations were of questionable status.

6.8.3.1 York Minster

It was assumed that, due to the auspiciousness of York Minster, this population would have had the lowest levels of asymmetry and proportionately the fewest outliers of all sample populations as it had potentially the highest status. As the city of York was both the social centre of Yorkshire and one of the most important ecclesiastical centres in England, York Minster would have been used not only by high status ecclesiastics but also the wealthy, aristocratic and royal (Milner 1961; Rollason 1999; Buckberry 2007). All individuals from the medieval sample were recovered from prominent burial locations (i.e. from within the Minster and in the Chapterhouse Yard). Although the relationship of the Anglo-Saxon church to the burials recovered is unknown, a high prevalence of charcoal burials and elaborate grave slabs also indicate a high status burial rite for the Anglo-Saxon sample (Hadley 2002).

Unexpectedly, subadults from York Minster had comparatively high average median DA and adults had comparable median DA to St. Helen's (one of the lowest status sites). These results suggest either that high levels of DA indicate individuals were engaged less strenuous occupations and DA is a result of normal activities influenced by handedness and footedness, or that these individuals were subject to greater unilateral biomechanical demands. There is a possibility that the high proportion of DA in this sample could be attributed to the inclusion of individuals of high standing that were trained in armed conflict. During data collection from the York Minster sample, it was noted that there was a comparatively high frequency of individuals with healed and perimortem injuries that could be associated with weapon-related trauma. As for the subadult sample, the cause of the increased directionality is unknown, as there has been limited research into subadult activity and resulting asymmetries. All of the subadults, except one individual, were under the age of 12 years, making it unlikely that DA is a reflection of increased biomechanical loading corresponding to the time when children took up adult levels of activity. It could be that the directional asymmetry found in the subadults is a measure of developmental instability rather than biomechanical stress.

As expected, the high status York Minster adult population had low levels of fluctuating asymmetry in the majority of measurements and indices. It also had the lowest average median FA scores after only Hereford and Fishergate. York Minster had proportionately fewer adult and subadult population outliers than the other sites, except the adult populations from Blackfriars and Hereford. These levels are consistent with the high status of York Minster. Although the subadult population had higher FA than at Wharram Percy, Hereford, and St. Helen's, it was found to have low FA when compared with the other sites. It is proposed that these higher levels of FA in subadults are evidence for the validity of the osteological paradox. The lower levels of FA in subadults from Wharram Percy and St. Helen's could be a reflection of the increased infant and childhood mortality reported at these sites. Of the sites included, subadult mortality in both the Wharram Percy and St. Helen's populations were greater than that at York Minster (see Table 3.3) suggesting that—by the tenets of the osteological paradox—subadults from the former sites were less able to buffer themselves against developmental insults and therefore died before asymmetry could accumulate.

Adults from York Minster may have developed higher FA than those at Hereford and Fishergate due to the poor environmental condition of the city of York, as demonstrated in Chapter 3. Although many of the wealthy preferred the countryside and suburbs of York, a proportion of those buried at the Minster would have been living and working within the walled city, especially the ecclesiastic and well-to-do merchants. They would have been subject to a similar environment as low status individuals, which has been found historically and archaeologically to have had high levels of environmental pollution (Miller 1961; Laing and Laing 1979; Addyman 1989; Kenward and Hall 1995; Dyer 2003). Those individuals interred at Fishergate, on the other hand, were living outside the walled city and thus free of many of the stresses incurred from living in the city itself. The privileged status of those interred within York Minster would have afforded them some advantages, but may not have completely buffered them from York's poor environmental conditions. Evidence of this comes from one of the high status named individuals from the York Mister population, Archbishop Greenfield (d. 1315). Although few measurements could be taken due to the poor preservation of his skeleton, a high degree of asymmetry existed in the femur in length (FA8=6.9%), maximum midshaft diameter (FA8=7.8%) and width of the proximal end (FA8=3.9%) (see Figure 6.35).

Figure 6.35: Asymmetry in the femora of Archbishop Greenfield (d. 1315) from York Minster.

6.8.3.2 Chelsea

Chelsea was consistently higher in asymmetry for the majority of measurements, indices and overall average median asymmetries than the majority of the other skeletal populations, apart from Wolverhampton and Hickleton. Due to the high status of the village of Chelsea, it would not be expected that these individuals would have such high levels of asymmetry. However, although a relatively affluent area, it is highly possible that the excavation of Chelsea Old Church recovered not only the wealthy residents but an admixture of the individuals from all levels of the town's society, including the very poor (Cowie *et al.* 2008). Chelsea's economy was not solely centred on catering to London's high society, as the majority of residents were engaged in agriculture and industry. Further evidence of low status individuals living in the parish was in the opening of a workhouse in 1735-7 for the poor, which had an increasing number of inmates over time (Currie 2004; Croot 2004a; Insley and Croot 2004; Cowie *et. al.* 2008).

Nevertheless, within the named sample from Chelsea even the higher status individuals exhibited a high degree of asymmetry. For instance, Robert Butler Esq. (d. 1712), who's occupation was listed as a gentleman in the church records (Cowie *et. al.* 2008), had an outlying measurement in talar length (FA8=8.3%, T_G= 4.415, $p<0.01$) and differences in fluctuating asymmetry of at least two standard deviations from the population mean in the fifth metatarsal length (FA=3.8%) and femoral length (FA=1.8%) (Figure 6.36). Even if the skeletal sample was mainly representative of the upper class, they would still have been subject to a great amount of environmental stress from its close proximity to London. Additionally, residents may have spent part of their time in the city for recreation or work. In 1858 and 1859 the Thames, which was one of the attractions of Chelsea, had become so polluted by the lack of proper sanitation that those who worked in the parliamentary offices would have to hang materials soaked in disinfectants to reduce the smell in order to permit them to carry out their work (Haley 1978). Similarly, although high status individuals had better access to foodstuffs, many of the luxury food items were contaminated by bacteria and foreign materials. A report by the Privy Council in 1863 revealed that at least one-fifth of all meat from butchers in England and Wales came from diseased cattle (Bentley 1971, Haley 1978, and Porter 1998). The environmental effect of the Industrial Revolution is further suggested by Chelsea having the highest frequency of rickets when compared with the other sites. It is likely that the asymmetry in this case does not exclusively reflect the social status of the site, nor is it an indication of biomechanical stress, but is primarily caused by environmental stress, which affected the majority of the population of England during the Industrial revolution regardless of class distinction (see Section 6.7 for a further discussion). However, when comparisons were made of only the post-medieval sites, Chelsea possessed the lowest levels of FA (apart from post-medieval York Minster, which consisted of a small sample size) suggesting that Chelsea's higher status may still have been beneficial to those buried at Old Church.

Figure 6.36: Femoral length asymmetry of Robert Butler (d. 1712) from Chelsea.

6.8.3.3 Hereford

Hereford had proportionately the lowest adult fluctuating asymmetry and population outliers of all included samples. Subadult levels of FA were also relatively low. These low levels imply that individuals at Hereford were living under comparatively low levels of stress and may thus be of higher status. This is consistent with the suggestion that the Anglo-Saxon individuals were of high status due to their burial position just east of a stone building (Stone and Appleton-Fox 1996). These levels also indicate that many of the individuals interred in this area of the cemetery during the Medieval period were of high status. As the position of the Cathedral and its out-buildings limited burial in the usually sought after southern section of the cemetery (Stone and Appleton-Fox 1996), normal inferences made of the social status of these individual from burial location does not necessarily apply. Although the location where the sample comes from was not usually considered to be a prominent burial area and this region of the cemetery was used for plague burials and for charnel (Stone and Appleton-Fox 1996), asymmetry levels suggest individuals buried here were not of low status. Due to the closeness of this area to the church building itself and to the altars inside, it is possible that this area was, in fact, a sought-after burial location. Furthermore, the existence of plague pits in this area may not be indicative of status, as it is highly possible that other areas of the cemetery were also being used in order to cope with a high mortality rate associated with the Black Plague. These levels of FA may support the hypothesis that this area of the cemetery was used by the parish of St. John (Stone and Appleton-Fox 1996), and that the area excavated was sought after by those individuals of higher status from this parish.

Hereford had the highest levels of DA, after the post-medieval samples, suggesting that these individuals would have been involved in heightened unilateral activities. However, as has been discussed, there can be many interpretations of the high levels of directional asymmetry found as a result of the current research. If these individuals were of relatively high status, and thus not engaged in the same level of strenuous activities that those from sites such as Towton and Wharram Percy were involved, it is possible that these results indicate that directional asymmetry was heavily influenced by the handedness and footedness of moderately active individuals.

6.8.3.4 Fishergate

The adult population of Fishergate had intermediate levels of median directional asymmetry; the second lowest levels of fluctuating asymmetry, after Hereford; and they had comparatively fewer population outliers than many of the other samples. This population exhibited lower levels of FA than even the high status site of York Minster, signifying that the individuals buried at this priory were of a relatively high status. This is converse to what historical records indicate about the status of the priory. Fishergate was known to be one of the lesser Gilbertine priories in the area and was never considered to be wealthy. In the 14th and 15th century the priory was impoverished and in disrepair (Stroud and Kemp 1993; Burton 1996; Kemp and Graves 1996). However, as it was deemed a privilege to be buried in monastic sites and individuals would have to pay for this right, the poor would not have been buried here (Stroud and Kemp 1993, Wiggins *et al.* 1993). Although the status of the surrounding lay population is not confirmed, it is known that the rich during the Medieval period usually preferred to live in the suburbs (Dyer 2003). The priory's location outside the city walls of York in the suburbs also would have meant that individuals from this site were not subject to environmental pollution on the scale of those living in the city centre. The general health of the Fishergate population was also comparatively better than many of the other included sites. Further, Fishergate had the highest number of individuals living beyond the age of 45 years (see Table 3.3).

In all the measurements and indices, the differing areas of the cemetery (high status and resident monastic burials within the church, lay population in the south cemetery, and the resident community in the east cemetery) were very similar in levels of FA. Those individuals buried in the east cemetery had slightly higher levels of FA in more traits than other burial areas, with 35, while those in the south cemetery had 30 and those in the church had 31. There were only five measurements (SAL, HXMS, SZS1, FLE, and FMLP) and one index (femur) that differed significantly between the areas ($p<0.05$) (see electronic appendix). Of these measurements, the east cemetery was found to be significantly higher than the other two areas, except for the SAL where those individuals buried within the church were higher and SZ1 where those in the south cemetery were higher. This indicates that the monastic community was under slightly more stress than the lay population. This could be evidence of that while the monastic community was under greater environmental stress due to the reported poverty of the priory, the local lay population were of better socio-economic standing as the result of their association with it.

Like many of the sites, the asymmetry of the subadult population is harder to interpret in light of the adult population's results. Fishergate subadults were higher in directional and fluctuating asymmetry and possessed a greater percentage of population outliers than the majority of the other samples. At face value, this suggests that the subadult population was under greater amounts of stress than many of the adult populations from other sites. In fluctuating asymmetry, it falls just after Chichester and the post-medieval samples, which have been demonstrated to be under considerable amounts of stress. Juvenile mortality at this site was comparatively lower than that at all the other sites, except York Minster and Chelsea (see Table 3.3). These mortality figures not only suggest this site was under reduced stress, it also suggest that juveniles were better buffered against environmental stress as they were surviving longer than those at the other sites. This is evident in the comparatively low percentage of the subadults dying before the age of 5 years. Fishergate subadults had the greatest survival rates, with the exception of Chelsea. These high levels of asymmetry may be a reflection of their survival; while at other sites subadults were not living long enough for asymmetries to accumulate.

6.8.3.5 Towton

The Towton population had the lowest levels of directional asymmetry. It would have been expected that due to the suggested heightened activity required by soldiering that Towton would have had higher levels of DA than the other sites. However, the opposite was found. The low levels of DA in Towton may be attributed to two factors: either individuals from this site were not seasoned soldiers, or that they were engaged in heightened bilateral activities. Although the Towton sample was from a battlefield site, it does not necessarily signify that these individuals were used to the physical demands of conflict. Many of these individuals could have been peasant conscripts and not all livery soldiers (Knüsel and Boylston 2000), which could be why Towton and Wharram Percy have similar asymmetry. Previous research established that the majority of the individuals were found to have average robusticity, while only a few individuals had bony changes that could be linked to strenuous activities suggestive of long term physical training in arms. These studies conclude that the symmetry in the humeri of the Towton individuals who exhibited a degree of robustness was due to a bilateral behaviour, such as archery (Knüsel 2000; Rhodes and Knüsel 2005; Blackburn and Knüsel 2006). Similar asymmetry patterns were found in individuals from the *Mary Rose,* which was concluded to be due to archery (Stirland 1993a; 1993b).

Individuals from Towton had the highest levels of fluctuating asymmetry after the post-medieval sites. The Towton population also possessed higher levels of FA than individuals from the contemporaneous hospital site of Chichester, which suggests that these individuals came from environments that were under a great amount of stress. If these individuals entered training at an early age (i.e. during ontogeny), it is likely the high FA indicates that a military life was not only hazardous, but that was also oppressive. Increased FA may also indicate that these individuals were from a lower status, most likely agricultural peasants. The fact that, after death, these individuals remained on the battlefield signifies that they were perceived to be unworthy of recovery for a church burial and therefore not of high status. Not only were there individuals known to have been conscripted for military duties, the warring factions also were known to pay a low wage to individuals to join their ranks, many of which would have been in a desperate situation (Knüsel and Boylston 2000).

6.8.3.6 Blackfriars

The excavated sample from Blackfriars was likely to be made up of the local lay population and did not consist of the resident population of the friary. Although the city of Gloucester enjoyed the status of being amongst the wealthiest English cities (Herbert 1988a, 1988c, 1988d), the status of its lay population buried at the friary is unknown. As Blackfriars had similar adult and subadult median fluctuating asymmetry levels to the *leprosarium*/almshouse site of Chichester, these levels may lend support to the hypothesis that Blackfriars may have been a working hospital (Wiggins *et al.* 1993). This is further supported by the high prevalence of periostitis, Blackfriars having the highest levels after Wolverhampton and Chichester, and the comparatively short statures of both the males (which had the second lowest) and females (which had lowest). Blackfriars' adult population also had the second lowest levels of directional asymmetry, which may indicate lower status if individuals were involved in increased bimanual activities to the same extent as Towton and Wharram Percy. Both DA and FA results are suggestive of a population that was living under comparatively higher levels of environmental and biomechanical stress. However, adults had the second lowest percentage of population outliers (after Hereford) and subadults were the third lowest (after St. Helen's and York Minster), which is suggestive of high developmental stability. This is puzzling as this is the only site in which levels of outliers within a population suggests the converse of what seems indicated by the levels of fluctuating asymmetry.

6.8.3.7 Wharram Percy

Much of the differences in the asymmetry of Wharram Percy have already been discussed in the previous chapters. Wharram Percy had relatively low levels of DA indicating that, like the Towton population, these individuals were likely to have been engaged in strenuous bilateral activities associated with agricultural work (although this would need to be verified through the analysis of robusticity markers). Levels of fluctuating asymmetry and the percentage of outliers indicate that Wharram Percy was under a comparatively average level of environmental stress. However, Wharram Percy was found to have higher levels of fluctuating asymmetry than the low status urban site of St. Helen's. It also had a greater percentage of population outliers than the post-medieval site of Chelsea and a similar percentage to that of Chichester. Historical and archaeological records indicate that throughout most of its occupation Wharram Percy was a poor rural village that suffered many years of hardship (Beresford and Hurst 1976, 1990; Beresford 1979, 1987). These results are consistent with what would be expected from their socio-economic status of agricultural labourers and a reflection of the site's rural location.

Wharram Percy subadults had the lowest levels of fluctuating asymmetry, comparatively few population outliers, and low levels of directional asymmetry. This at first seems to indicate that these subadults were enjoying a lower level of environmental stress. However, Wharram Percy had the highest juvenile mortality of the included samples with a comparatively high percentage of these subadults dying before the age of 5 years (see Table 3.3). The mortality rate for those less than 5 years (63.3%) is comparable to that of St. Helen's (63%). Again, this is suggestive that subadults may not have been surviving long enough for asymmetry to be detectable. Hence the population of Wharram Percy may have been under a considerably higher amount of environmental stress than the results suggest.

6.8.3.8 St. Helen's

Archaeological and historical evidence indicated that St. Helen's possessed one of the lowest inferred socio-economic statuses of all the sites included. The surrounding parish had some of the lowest rents in the city and the church was ranked lower than the majority of York's churches. Regardless of its rank, records indicate that there were still individuals of middle to high status being buried in the church (Palliser 1980; Jones 1988). As a result of the current research it was found that, even though they had a low socio-economic status, the St. Helen's sample population had the fourth lowest average median fluctuating asymmetry for adults, with levels similar to those from Wharram Percy. However, cemetery sites with higher levels of FA than that at St. Helen's were also either of low socio-economic status or were from the stressful environment of the Industrial Revolution. These sites were Wharram Percy, a rural agricultural village of low social-economic status; Blackfriars, a suspected hospital; Chichester, a *leprosarium/ almshouse*; soldiers from Towton; and the highly stressed post-medieval populations. St. Helen's adult population had a comparatively high percentage of population outliers, coming only after those of Wolverhampton and Hickleton. This is also consistent with the inferred low socio-economic status of St. Helen's.

Subadults had the second lowest levels in both directional asymmetry and percentage of population outliers. They also had the third lowest levels of fluctuating asymmetry. This appears to suggest that these subadults were better buffered from environmental stress than those at other sites. However, the juvenile mortality rate was comparatively higher than the other sample populations. Of the total recovered subadults, 63% of St. Helen's subadult population died before the age of five. The young age of this cemetery's subadult population would indicate that there was a limited accumulation of asymmetry in the total subadult population from this site and, therefore, suggestive of a highly stressed environment.

When all adult measurements and indices were compared separately for each of the main areas of the cemetery (within the church, the south cemetery, and in the north cemetery), individuals buried in the south had a greater number of measurements (48) and indices (15) that had higher FA than the other two areas, while individuals interred in the north came second (greater in 32 measurements and 9 indices) and those buried within the church had the lowest (greater in 21 measurements and 7 indices) (see electronic appendix). However, there were only two measurements (MC2L and FAPH) and one index (upper long bone lengths) that significantly differed between the specific burial areas ($p<0.05$)(see electronic appendix). This indicates that although those buried in the southern cemetery had greater levels of FA, these differences were not significant and the overall developmental stability of the site was similar.

6.8.3.9 Chichester

Not surprisingly, the *leprosarium/*almshouse site of Chichester had comparatively high levels of fluctuating asymmetry and population outliers for both adults and subadults.

Apart from the post-medieval populations, the only other site to have greater FA was found to be the battlefield site of Towton, and the only site greater in population outliers was the low status site of St. Helen's. It has been demonstrated that there is a connection between poor health and an individual's inability to properly buffer against environmental stress (Møller and Swaddle 1997; Gangestad and Thornhill 1999; Leamy and Klingenberg 2005). If we make the assumption that a high level of fluctuating asymmetry, and thus developmental instability, predisposes an individual to a higher likelihood of contracting an illness, then it would be expected that many of those individuals buried at Chichester were already disadvantaged during ontogeny. It is likely that these asymmetry results indicate that the majority of those individuals buried at the hospital came from low socio-economic backgrounds, which would have predisposed them to disease. Although leprosy has been known to have afflicted individuals from all levels of society in the past, there is a strong association with poverty (Magilton 2008d). In addition, once the hospital was converted into an almshouse, Chichester's population would have also been of low socio-economic status. Furthermore, historic records indicate that hospital life was deprived, with inmates following a strict regime of poverty (Clay, 1966; Magilton 2008d).

A comparison of both Areas A and B indicated that individuals had similar levels of asymmetry regardless of location, indicating that levels of asymmetry remained constant throughout Chichester's occupation (see electronic appendix). Area A, suspected to be the first phase of the cemetery consisting of the leper hospital, had slightly more measurements that were higher than those related to the later occupation of the site, with 53, while Area B had 47 traits that produced higher levels of asymmetry. Area B, on the other hand, had 15 indices higher than those of Area A, which had 13. Of these, only eight measurements and three indices significantly differed ($p<0.05$). Area B was significantly higher in six measurements and one index (COPO, CLAST, HXMS, HDT, CZL and the mandible), while Area A was higher in two measurements and two indices (MC2L, FEB, the femur, and the sacro-iliac joint).

The high levels of asymmetry and population outliers in the subadult population also brings into question whether or not the children buried at Chichester were inmates from the hospital or if they were from the population of the surrounding area. As Lewis (2008) points out, although there is no documentary evidence for leprous children or subadults being interred during the almshouse phase, children were known to be especially vulnerable to leprosy and poverty. In her study, she also found that children at Chichester were disadvantaged in growth and that 24.8% had evidence of chronic disease. At this site, the high levels of fluctuating asymmetry in the subadult population are indicative of high levels of environmental stress or decrease in their ability to buffer against such stress. If the subadults were inmates during the hospital or almshouse phase, they would have been under the similar high levels of environmental stress as the adults at this site (or they were drawn from the same stressed population).

Both adults and subadults from the Chichester sample also exhibited increased levels of average median directional asymmetry. This implies that the Chichester population were involved in heavy manual labour, and were possibly agriculturalists or poor urban workers, and thus were not of higher social standing. However, there was not a specific area of the skeleton where it exceeded the levels of directional asymmetry in other populations. When measurements are examined individually, Chichester was average for directional asymmetry in most measurements (see appendix 8). The sum total of directional asymmetry in this sample may be indicative of biomechanical changes associated with an altered gait and long-term bed rest due to ill health. It is also possible that the resulting DA scores have been inflated by the high levels of fluctuating asymmetry.

6.8.3.10 Wolverhampton

The skeletal population from Wolverhampton was consistently amongst the populations with the highest levels of fluctuating and directional asymmetry. This sample was only lower than Chelsea in adult directional asymmetry and Hickleton in fluctuating asymmetry. Subadults from this site were also the third lowest in directional asymmetry, after Hickleton and St. Helen's. Directional asymmetry results indicate that the adults were engaged in increased unilateral activities, which is likely to be associated with the occupations in specialised crafts or industry that was mentioned in the parish burial records (see Galloway 2002 and Chapter 3). The comparatively low levels of DA in the subadult population suggest that these individuals were not subject to the same work load as the adult group or that they were dying before they reached an age where activity levels had an effect on the rate of bone growth.

Fluctuating asymmetry and population outlier results indicate that the Wolverhampton population had decreased developmental stability, which was likely due to elevated environmental stress caused by the Industrial Revolution. As has been discussed in Section 6.7, the post-Medieval period was subject to significantly higher levels of environmental stress. Wolverhampton was located at the heart of the Black Country. During the cemetery's short period of use, individuals would have been living at the height of the Industrial Revolution in Wolverhampton. Air pollution would have been an ever increasing problem as coal was burned regularly in over 100 furnaces. Additionally, in an 80 year period from 1801 there was a drastic population increase in the city of over 68,000 people (Farley 1985; Parker n.d). This rise in population was the cause of much of the increased environmental stress, which the city failed to improve upon. There was an increase in housing density and poor sanitation. The working class, which made up most of the cemetery's population, was known to be subject to epidemics, malnutrition, and a high mortality rate (Farley 1985; Coates and Nielson 2002; Adams and Driver 2007). As the life expectancy at birth was only 19 years old and one in six children died before one year (Adams and Driver 2007), it is proposed that the high levels of asymmetry revealed in the current study would have been even higher if the subadult population had survived to adulthood.

6.8.3.11 Hickleton

The social status of those living in the parish of Hickleton during the Medieval and post-Medieval periods is unknown. As the individuals were interred within the church, it is assumed that they were likely to have been those with high social standing within the local community. Although there was a family that had a grand manorial estate in the village during these periods, these individuals may have preferred to have been buried in a higher status cemetery away from their local parish. It was the remaining labouring population of Hickleton that would have made use of the local church. Unfortunately, as there is not a readily available history of the village and the church, and the excavation report still remains to be written, historical and archaeological comparisons of socio-economic status with asymmetry cannot be made sufficiently at this time.

The adult population of Hickleton was comparatively higher in directional and fluctuating asymmetry than the other included sites. Results from directional asymmetry analysis suggest that the adult population was engaged in unilateral activities, which are likely associated with agricultural and/or specialised crafts of the rural countryside. The subadult group from this site had average levels of median asymmetry, leaning towards symmetry at -0.01%. These results seem to suggest that either the subadults were inactive or that they were engaged in bilateral activities. Similar to directional asymmetry results, Hickleton had highest adult fluctuating asymmetry and it was the second highest for subadult fluctuating asymmetry and adult population outliers. Hickleton subadults also had the third highest percentage of population outliers. These fluctuating asymmetry and population outlier results indicate that although these individuals may have been of high standing within the village, they were under considerably high levels of stress, which remained constant throughout the Medieval to post-Medieval periods. These stress levels are consistent with historical evidence of environmental and socio-economic stress in rural areas of England, especially during the post-Medieval period. As mentioned in Chapter 3, many of the rural settlements during the post-Medieval period found the population living in poor environmental and sanitary conditions, subject to low wages, high taxes, poor nutrition, inadequate poor relief, and many individuals experienced long periods of unemployment (Chadwick 1965; McCord 1991).

6.8.4 Summary

Directional asymmetry was found to be a poor indicator of socio-economic status when compared with the historical and archaeological record. Although previous research has indicated that a high degree of directional asymmetry is suggestive of repeated strenuous unilateral activity in modern athletes, the lack of asymmetry has also been linked to increased activity (for a review see Ruff 2000; Steele 2000b). The use of directional asymmetry is problematic due to such diversity in human activity. In order to utilize DA in this manner, a comparison of asymmetry to robusticity and other skeletal markers of activity (e.g. enthesis and cross-sectional analysis) would have to be undertaken.

On the other hand, fluctuating asymmetry and especially population outliers were found to have a positive correlation with historical and archaeological suggestions of socio-economic status. Those populations with low socio-economic status had comparatively increased developmental instability, which could be related to environmental stress (such as poor sanitation, increased population density, environmental pollution, poor nutrition, and poor health). However, it was demonstrated that individuals of high social standing also exhibited elevated levels of fluctuating asymmetry. This is evidence that, although the high status individuals experienced a degree of environmental stress, they had survived that stress.

Chapter Seven

Conclusions

7.1 Conclusions

The primary conclusions of this thesis are:

- The normal average median range of asymmetry is from -5.79 to 6.62% for directional asymmetry (DA) and from 0 to 6.53% for fluctuating asymmetry (FA).
- Asymmetry is trait specific.
- The most informative traits are long bone maximum lengths, *os coxae* height and ischial length, and cranial measurements *lambda-frontomalare* length, *nasion-orbitale* breadth, *bregma-zygoorbitale* length, *nasion-mastoidale* length, and *frontomalare-nasion* length.
- The least informative traits are mastoid process height, digastric groove length, and clavicular medial and lateral curvature depths.
- The cranium's predominance for favouring the right-side is due to both underlying cerebral asymmetry and developmental conditions.
- Right-side dominance in the upper limb is established at an early stage in development through manipulative behaviour and is not genetically controlled.
- Asymmetry in the clavicle begins to accumulate during the earliest stages of development and remains asymmetric throughout life.
- Asymmetry in the pelvis reflects load transfers from the upper and lower limbs.
- Asymmetry in the lower limb diminishes in the distal leg segments.
- The lower limb favours symmetry in order to provide stabilization and co-ordinated locomotion.

- Frequencies and extent of population outlying measurements are effective measures of developmental instability and congenital conditions.
- Differences in directional asymmetry between males and females occurred solely in the upper limb, while fluctuating asymmetry was more widely distributed throughout the skeleton.
- Males had greater fluctuating and directional asymmetry in midshaft dimensions, areas of muscle attachments and articular dimensions that favoured the right side, while females were more asymmetric in limb lengths. These may be indicative of sexual division of labour/activity.
- Females appear to be less able to buffer environmental stress, especially during ontogeny, while males were susceptible to insults over a greater period of time.
- Directional asymmetry increased with age during ontogeny, being greatest during the late childhood and adolescent growth spurt, while DA stabilized during adulthood, having only a slight increase with age.
- Subadults appear less able to buffer environmental stress than adults.
- Levels of directional asymmetry suggest similar activity levels existed between rural and urban settlements.
- High levels of fluctuating asymmetry in rural populations indicate they were under greater environmental stress than urban groups.
- There was a significant diachronic increase in asymmetry caused by the adverse effects of industrialisation.
- Directional asymmetry is a poor indicator of socio-economic status because it may be time and context specific.
- Levels of fluctuating asymmetry and frequencies of population outlying measurements provide a valid assessment of socio-economic status in the past.

This study has established a baseline for the normal range of variation in asymmetry for both adult and subadult archaeological populations from England. Future researchers will be able to quickly make population comparisons and assessments of individual levels of asymmetry with the expected 'normal' range of asymmetry within other archaeological populations. They will be able to assess whether or not a population or an individual possesses abnormal levels of asymmetry, informing them of possible population differences in manipulative behaviour and/or whether or not their population/individual exhibits increased developmental instability. On average, normal levels of asymmetry for these English populations fall between -5.79 to 6.62% for directional asymmetry (DA) and from 0 to 6.53% for fluctuating asymmetry (FA). However, this study supports the conclusions of previous research that asymmetry is trait specific. It is therefore suggested that generalisations should be avoided unless they are accompanied by analysis of individual measurements, as each trait has a distinct normal asymmetry range. Asymmetry levels can range from anywhere as high as -30.72 to 30.92% for directional asymmetry and from 0 to 31.76% for fluctuating asymmetry; and can be as low as -1.75 to 1.37% for directional asymmetry and from 0 to 1.7% for fluctuating asymmetry. The most informative traits for population comparisons of asymmetry are long bone maximum lengths, *os coxae* height and ischial length, and cranial measurements *lambda-frontomalare* length, *nasion-orbitale* breadth, *bregma-zygoorbitale* length, *nasion-mastoidale* length, and *frontomalare-nasion* length; as they have the highest accuracy, lowest average levels of asymmetry, and lowest standard deviations. The most variable traits, and thus the least informative, are mastoid process height, digastric groove length, and clavicular medial and lateral curvature depths. These measurements perform poorly in population comparisons of asymmetry because of their broad range of variation.

This research supports the findings of previous studies on the patterning of asymmetry throughout the skeleton. The current study found the cranium to be a normally asymmetric structure prone to the right-side dominance, which can be attributed to not only underlying cerebral asymmetries but also to disturbances in the developmental environment. The upper limb of adults and subadults was found to be significantly right-side dominant. This laterality of the upper limbs is established at an early stage in development. However, as demonstrated in maximum lengths of the upper limbs, especially that of the humerus, laterality is unlikely to be genetically controlled. Instead, this research lends further support to the hypothesis that directional asymmetry has its origin in manipulative behaviour. The only exception to this is the clavicle as it was found to remain asymmetric from early ontogeny to mature adulthood, which may indicate a genetic origin. Clavicular asymmetry may be a reflection of underlying asymmetries of the soft tissue of the thorax, similar to that noted in the cranium. Moving inferiorly, asymmetries in the pelvis followed the path of load transfers across the elements to the upper and lower limbs and are influenced either by activities of the upper limb or by asymmetric gait. Asymmetry was found to diminish in the distal leg segments, most likely due to the structural requirement for symmetry to provide stabilization and co-ordinated locomotion. This being said, the femur was found to be the most asymmetric element in the lower limb, with maximum length and diaphyseal measurements having small but significant left-side dominance. This trend for symmetry is established at the beginning of ontogeny and remains at similar levels throughout life.

This is the first study to demonstrate that population outliers from asymmetry studies can be used as a measure of the presence and extent of developmental instability and congenital/developmental conditions within archaeological populations. While it is agreed that population outliers should be removed from the actual calculation of population levels of asymmetry, it is suggested that these population outliers, by their very nature, provide valuable insight into both population level developmental instability and individual capacity to buffer against environmental and genetic stress. It is proposed that instead of disregarding outlying measurements, future asymmetry studies should include a discussion on these outliers as a measure of developmental stress and as a means to identify potential congenital/developmental conditions in the past.

The cause of deviations from 'normal' levels were found to be a complex mixture of both directional and fluctuating asymmetry affected by population demographics (i.e. age and sex), settlement location, diachronic origin of populations, and socio-economic differences between them. There were few significant differences found between the sexes in fluctuating and directional asymmetry. Although not significantly so, males had a greater percentage of outlying measurements than did females. Almost all of the significant differences between males and females for directional asymmetry were located in the upper limb, whereas significant differences in fluctuating asymmetry were more widely distributed throughout the skeleton. Males had greater fluctuating and directional asymmetry in midshaft dimensions, areas of muscle attachment and articular dimensions which favoured the right side, while females were more asymmetric in limb lengths. The results of directional asymmetry suggest that there was a sexual division of labour/activity, with females involved in more unilateral activities and males more bilateral activities. Contrary to previous studies, this pattern of fluctuating asymmetry implies that females were less able to buffer from environmental stress during ontogeny. This is suggested in the greater levels of fluctuating asymmetry in female limb lengths, growth of which ends during adolescence, signifying that they were more susceptible to or under higher stress than males during ontogeny. Males, on the other hand, were found to be more susceptible to stress over a greater period of time. It is also possible that decreased asymmetry in males was due to a greater number of episodes of cessation of growth caused by increased developmental stress; therefore, an accurate measure of developmental stress in males would not be possible through the analysis of asymmetry.

Significant age-related changes in asymmetry and frequency of population outliers were found. Directional asymmetry increased with age during ontogeny, being greatest during the late childhood and adolescent growth spurt, while DA stabilized during adulthood, having only a slight increase with age. This period of life course coincides with the age at which individuals entered employment in the past. Although fluctuating asymmetry was found to increase with age during adulthood, unlike directional asymmetry, subadults were found to have greater levels of fluctuating asymmetry and a higher percentage of population outlying measurements than adults. Fluctuating asymmetry was at its highest during foetal development and infancy, and then again in adolescence. This suggests that subadults were less able to buffer against environmental stress than the adult population. These results are indicative of an underlying difficulty of the skeletal system in maintaining homeostasis during stages of rapid growth and the body’s ability to regain symmetry before ontogeny is completed.

Although some inferences can be made about differences in asymmetry between subadult and adult populations, the osteological paradox must be taken into account when evaluating results from measurements of subadult material. When analysing results from subadult populations, it must be taken into account that these individuals died before ontogenesis was completed. There are two possible interpretations of the extent of asymmetry in subadult populations. First, subadults that presented asymmetry were able to buffer against environmentally generated disturbances long enough for resulting asymmetry to be detectable. Subadults that lacked asymmetry were either under greater stress, or they had even more deficient buffering capabilities than the surviving population. This would imply that the population in question was under substantial environmental stress. On other hand, it is possible that if a subadult population was found to have decreased levels of fluctuating asymmetry and fewer population outliers, then that population was not under a significant amount of stress. Along with other stress markers, subadult asymmetry levels lend an incomplete picture of developmental instability. Therefore, interpretations of any results from the analysis of fluctuating asymmetry and the percentage of population outliers in subadult populations should be done with care and in conjunction with infant and childhood mortality rates.

Although there was found to be little difference in directional asymmetry between settlement types, subadult and adult populations demonstrated a distinct urban-rural divide in fluctuating asymmetry and population outliers. Similar directional asymmetry levels in both the urban and rural populations existed, with rural environments only slightly higher, indicating that both urban and rural groups developed increased laterality. The usefulness of directional asymmetry in detecting differences between these populations is problematic. As bone morphology is influenced by a multitude of different activities, it is difficult to make specific inferences about differences in past behaviours based solely on directional asymmetry. An absence of asymmetry could indicate increased general bilateral activity, an unusual number of left-handers within a population, or decreased levels of activity. Without subsequent biomechanical analysis of stress markers such as enthesopathies, perhaps combined with cross-sectional limb bone analysis, interpretation of low and high levels of asymmetry are problematic.

Both frequencies of population outliers and levels of fluctuating asymmetry in the adult population clearly indicated that rural populations were under greater environmental stress than their urban counterparts. Adults from rural environments had increased developmental instability, similar to stress levels of the *leprosarium* and almshouse population of Chichester. Subadults, on the other hand, exhibited a greater extent of fluctuating asymmetry and a higher percentage of measurement outliers in the urban group. This either indicates that, according to the osteological paradox, rural subadults were under such great stress that they were dying before asymmetry could accumulate, or that the subadults in the urban environments were more susceptible to urban pollution than the adult population. Subadult mortality figures for the sample populations included here suggest that the former is more likely to be the case. As discussed in chapter 3, although urban environments have evidence of increased environmental pollution, rural populations were living in relative poverty. Individuals in the countryside had poor nutritional intake, poor sanitation and hygiene, and lacked access to sufficient medical facilities.

The most striking results of this study were the differences between time periods. Population samples indicate a significant diachronic increase in asymmetry and the percentage of population outliers in both subadult and adult English archaeological populations. As there were only a few significant differences in directional asymmetry between periods, but many for fluctuating asymmetry, environmental factors other than biomechanical ones can be concluded to be the cause of this asymmetry. As demonstrated by higher fluctuating asymmetry scores and increased percentage of population outliers, the post-medieval population samples suffered greater developmental instability as result of the Industrial Revolution. Environmental stress during the post-Medieval period included an increase in population density, urban and rural poverty, increased pathogen load, environmental pollution (especially air pollution), and poor sanitation not seen to the same extent in other time periods.

Finally, a comparison of historic and archaeological accounts of socio-economic status with the magnitude of asymmetry and the percentage of population outliers provide a valid assessment of socio-economic status in the past. As stated above, due to the complex causes of activity-related changes in skeletal material, directional asymmetry appears to be a poor indicator of socio-economic status. Developmental instability influenced by the socio-economic standing of a population was discernible from fluctuating asymmetry and the frequency of outliers. As a general rule, populations of high socio-economic standing have an increased buffering capability. Populations with higher fluctuating symmetry and more population outliers, thus decreased developmental instability, came from environments with increased stress in the form of poor sanitation, increased population density, environmental pollution, poor nutrition, and poor overall health. However, diachronic differences in environmental stress had the greatest influence in the expression of asymmetry, as high social standing did not completely shield an individual from developmental disruptions.

Overall, this research has established a baseline for normal asymmetry values for English archaeological populations from the late Anglo-Saxon to the post-medieval periods. Deviations from normal population levels of asymmetry are due to a complex mixture of biomechanical and environmental stresses influenced by population demographics (i.e. age and sex), settlement type, socio-economic status, and period-specific origins of the sample populations. Possible causes of asymmetry could be discerned from comparisons of the levels of population asymmetry when placed in the context of physical activity, social networking, health, and environment as developed from the historical, archaeological and osteological record.

7.2 Future Research

This research was conducted in such a way that future analysis of asymmetry can easily be added to the dataset, not only for English archaeological populations but also for comparisons with modern and archaeological populations across the world. Any addition to this database will advance our overall understanding of what constitutes normal levels of asymmetry and what deviations from this norm might suggest about the environment of past and present populations. The inclusion of additional rural and post-medieval samples may further support the findings of the current study that these populations were subject to unusually high levels of environmental stress. This research would also benefit from the inclusion of additional populations of upper and lower status, which can be historically documented, in order to add to the understanding of the particular environmental stresses that influence developmental stability. Also, with research into subadult sex determination techniques gaining prominence, future research into sex-related asymmetry of subadults may answer the question of whether or not the significant differences noted between the sexes in adult populations have their origin in sexual division of labour, as inferred from the study of directional asymmetry, or are due to the differences in the treatment of or the developmental environments of males and females, as measured by fluctuating asymmetry.

Although asymmetry has been found to be a useful indicator of biomechanical and environmental stress, asymmetry studies would benefit from the inclusion and analysis of other skeletal stress indicators. As interpretations of past activities from directional asymmetry alone were found to be inconclusive, other biomechanical studies based on enthesopathies and cross-sectional analysis are recommended in order to differentiate between low asymmetry levels related to decreased activity or those caused by an increased bilateral loading. Similarly, although conclusions could be reached about the developmental stability of the sample populations, these would be strengthened with the analysis of other skeletal stress indicators, such as dental enamel hypoplasia as well as through studies of juvenile growth and adult stature.

There is a need to further explore the relationship of population outlying measurements and congenital conditions and how these relate to the developmental stability of a population. Extreme measurements that fell outside the 95% confidence interval and Grubb's population outliers in many individuals were indicative of underlying developmental/congenital conditions. This suspected relationship indicates that a full review of all skeletal remains of individuals with extreme asymmetry measurements could considerably add to the under-reporting of such conditions. In conjunction with historical documentation and archaeological context (such as burial placement and inclusions) such research could also shed light on social attitudes toward and treatment of those afflicted with congenital/developmental conditions in past human groups.

Lastly, study of fluctuating asymmetry in modern populations will not only add to our understanding of the influence of environmental conditions on past populations, it also promises to provide a measure of population stress today. Today, researchers in biology employ studies of fluctuating asymmetry in insects and animals to monitor environmental pollution. Only a few anthropologists undertake similar studies in modern human populations. Although animal models are informative, non-invasive studies of skeletal and living human populations could potentially provide comparable data to address the influence of environmental pollution, global warming, increased world population density and dispersal, as well as poverty in both the developing and developed world.

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